STUDY REPORT

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Fire behaviour of HVAC duct and pipe insulation materials

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Preface

This report was prepared during research into the fire behaviour of HVAC duct and pipe insulation materials and the test methods available for evaluating the potential hazard when these materials are involved in a fire.

Acknowledgments

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Note

This report is intended for regulatory authorities, building designers, manufacturers and suppliers of HVAC ductwork and pipe insulation materials.

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Fire behaviour of HVAC duct and pipe insulation materials

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Reference

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Abstract

This report describes an investigation of the fire behaviour and fire test methods used for combustible duct and pipe insulation materials intended for installation within New Zealand buildings. The study considered both rigid and flexible duct and pipe applications and included full-scale room fire testing of polyester-insulated ducts.

It is concluded that the fire method AS 1530.3 (and therefore AS 4254) does a poor job in discriminating fire performance and hazard of thermoplastic ductwork insulation. The Group Number system currently used for wall and ceiling surface linings provides a better means of assessing the likely contribution of a duct material to a developing fire.

A deemed to comply classification for polyester flexible ductwork is proposed, with other duct materials evaluated using ISO 5660 or ISO 9705. Duct materials should be assessed in a flat sheet configuration the same as for a wall or ceiling lining. EN-certified products should also be accepted.

It is recommended that the fire properties of external surface finishes of HVAC ducts be regulated in similar situations as would be required for wall and ceiling materials.

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1. INTRODUCTION

1.1 Objective

To investigate fire test methods for evaluating the fire hazard of both rigid and flexible combustible duct and pipe insulation materials intended for installation within New Zealand buildings.

To make recommendations on the fire test methods and acceptance levels suitable for use within New Zealand's regulatory environment.

1.2 Scope

This investigation is primarily concerned with the reaction to fire behaviour and properties of combustible materials used for insulating ducts and pipes within buildings. These typically form part of heating ventilating and air conditioning (HVAC) or fluid distribution systems. Reaction to fire is a term used to describe the behaviour of a material or system to a growing fire, considering the potential for surface spread of flame, heat release and smoke development. Combustible duct and pipe insulation materials can contribute to the overall fire hazard within buildings, placing occupants at increased risk while attempting to escape.

Where ducts and pipes pass through fire-rated construction (e.g. walls, ceilings), use of fire dampers or fire-resistant ductwork are additionally required to mitigate against fire spread through these construction elements. That aspect of fire-resisting performance is not part of this investigation.

2. BACKGROUND

In April 2012, new Building Code Clauses C1 to C6 (Tizard, 1992) and associated compliance documents came into effect (and subsequently became mandatory in April 2013 after a 12-month transition period). This included a shift in the reaction-to-fire test methods used for wall and ceiling linings, ducts and pipe insulation.

New requirements made use of a Group Number regime derived from actual or predicted behaviour (time to flashover) in a small room fire test. Actual behaviour refers to performance in the ISO 9705 room fire test (ISO, 2009) where time to flashover is measured. Predicted behaviour refers to a bench-scale 'cone calorimeter' test ISO 5660-1 (ISO, 2012) on small samples of product/material, where data is used to predict the time to flashover in the ISO 9705 test. Previously, data from AS 1530.3 (Standards Australia, 1999) had been used to regulate fire hazard properties of these building elements including ducts and pipe insulation. This test is often referred to as the 'early fire hazard test'.

In addition to new Building Code Clauses, a verification method C/VM2 (MBIE, 2014a) was published. This described a framework for fire safety design of buildings for compliance with the New Zealand Building Code (NZBC). A new set of Acceptable Solutions C/AS1 to C/AS7 applying to different building types or risk groups were also published (MBIE, 2014b). C/VM2 Appendix A contains normative requirements for establishing the Group Numbers for materials and is referenced by the Acceptable Solutions.

In December 2013, Appendix A C/VM2 was amended. The change allowed AS 4254 (Standards Australia, 2012a,b) – ductwork for air handling systems in buildings – to be optionally used for assigning a material Group Number for duct surfaces. This applied to both the internal and external surfaces of ducts used in HVAC systems. AS 4254 requires, amongst a range of measures, exposure to the UL 181 burning test (Underwriters Laboratories, 2013a) and testing to AS1530.3 as was previously required pre-April 2012.

Concern has been expressed by some sectors of the industry that a return to the AS 1530.3 testing regime for flexible ductwork poses a potential risk to occupants of buildings. This is because the AS1530.3 fire test potentially underestimates the contribution that some foil-faced polymeric materials make to the fire hazard. This is partly because these materials shrink away from the heat source under the test conditions where there is no direct flame contact. The behaviour can be quite different when the material is exposed to direct flame impingement in the presence of an imposed radiant heat source as might occur in a real fire. AS1530.3 also has other weaknesses. These include an unreliable smoke measurement and a maximum heat flux that is less than the flame heat flux typically expected from a moderate-sized flaming heat source contacting a solid surface.

This investigation reviews the relevant test methods and surveys the literature. A series of fire experiments are also conducted to assist in determining the behaviour of combustible duct and pipe insulation materials installed within buildings.

3. FIRE INCIDENT DATA

3.1 New Zealand

Fire incident data over the period 2000 to 2014 was obtained from the New Zealand Fire Service (Quirke, 2015). The data was used to assess the extent to which duct and pipe insulation materials may have played a role in fire incidents attended by the Fire Service. Based on the incidents reported, an estimate of the maximum number of potential fires involving duct materials, duct insulation or pipe insulation was made. The number was recorded where any of the following characteristics had been noted in the fire incident report:

- Origin location (duct – air, heating, cable, exhaust).
- First object ignited (pipe, duct, conduit, hose).
- Second object ignited (pipe, duct, conduit, hose).
- Avenue of flame (air handling duct).
- Avenue of smoke (air handling duct).
- First object ignited (lagging – conduit covering, other insulating material).
- Second object ignited (lagging – conduit covering, other insulating material).

Figure 1 shows the estimated total potential fires in single houses and in all property types that may have involved duct materials and insulation or pipe insulation over the period 2000 to 2014. The number of these fires as a percentage of the total number of fires in structures is also shown for all property types.

Additional fire incidents attributed to central heating equipment were not included in Figure 1.

It can be seen that about 2% of total reported structure fires were identified by the Fire Service as potentially involving duct materials and insulation, pipe insulation or lagging products. This is a relatively small proportion. Some caution should be applied in interpreting the incident data. This is because it may be difficult for firefighters to determine the extent that duct and pipe insulation materials contributed or not to the fire growth. This is especially the case when the materials were not the first item ignited or were located in cavities or ceiling spaces.

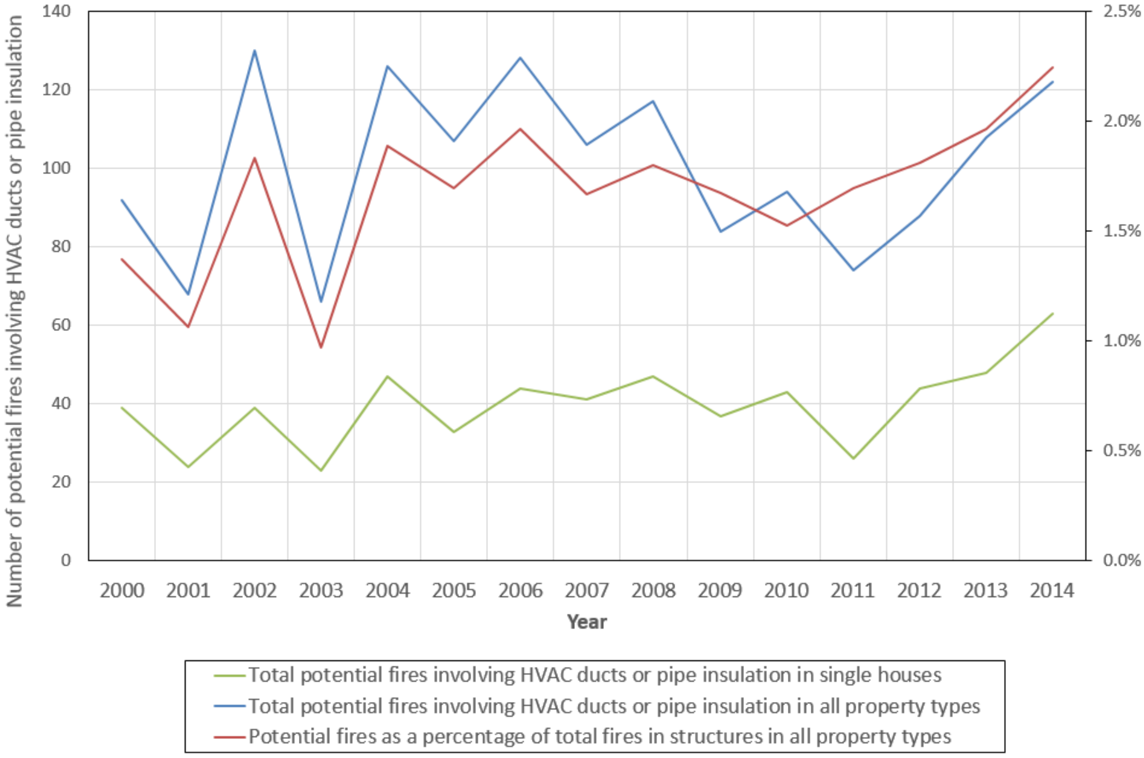


Figure 1 Estimated maximum possible reported fires associated with HVAC ducts or pipe insulation

3.2 London Fire Brigade

As part of a study investigating dampers and ducts for the Office of the Deputy Prime Minister (ODPM) (BRE, 2005a), the Building Research Establishment obtained data from the London Fire Brigade. Data on fires involving HVAC systems for different property types was examined. The time period over which the data applied was not reported. However, it is interesting to note in Table 1 that the proportion of fire in dwellings is comparable to those for single houses in the New Zealand data.

Table 2 shows the causes of ignition of fires involving ductwork with electrical wiring/insulation being the highest (24%) and insulation also shown (14%). Table 3 shows the materials that made the most contribution to fire spread where ductwork was involved.

It is noted that most HVAC ducting used in England is non-combustible and fires that involve ductwork may not be related to combustible ductwork.

Table 1 London Fire Brigade fires involving HVAC systems (extracted from BRE, 2005a)

Property type	Number of fires involving HVAC systems	Number of fires that spread beyond room of origin
Assembly	78	17
Car park	2	0
Commercial	3	2
Dwelling	357	43
Industrial	40	5
Institutional	17	2
Medical	20	2
Office	79	0
Other	11	1
Shop	90	18
Storage	3	1
Total sample	**700**	**73**

Table 2 London Fire Brigade causes of ignition involving ductwork (adapted from BRE, 2005a)

Material first ignited	Number of fires	% of total sample
Electrical wiring, insulation	169	24
Fat, oil, food residue, soot, grease, dirt	105	15
Fluff, dust, airborne particles	64	9
Extractor fan casing, vent casing, fan components, grille	73	10
Accumulated debris, refuse, rubbish	22	3
Electrical equipment, component	39	6
Flammable vapours, propellant	9	1
Air filters, dust filters	11	2
Insulation	99	14
Flooring, joists, timber boarding, plastic sheet, building components, sealants, wall panel, adhesive	14	2
Paint particles, paint	2	0.3
Natural gas	1	0.15
Furnishings, fittings	22	3
Storage, paper, tissue, tyres, scaffold boards	11	2
Unknown or not easily categorised	59	8
Total	**700**	**100**

Table 3 London Fire Brigade materials involving ductwork that made the most contribution to fire spread (adapted from BRE, 2005a)

Materials that made the most contribution to fire spread	Number of fires	% of total sample
Electrical wiring, insulation, trunking	38	5
Fat, oil, food residue, soot, grease, dirt	84	12
Fluff, dust, airborne particles	10	1
Extractor fan casing, vent casing, fan components, grille, air vents, plastic duct, air conditioner components, cooker hood	141	20
Accumulated debris, refuse, rubbish	5	1
Electrical equipment, component, appliance	29	4
Flammable vapours, propellant	4	1
Air filters, dust filters	41	6
Insulation	16	2
Flooring, joists, timber boarding, plastic sheet, building components, sealants, wall panel, adhesive, roof construction materials, ceiling, duct enclosure, timber ducting, door	74	11
Paint particles, paint, painted surfaces	4	1
Natural gas, petrol, fuel	4	1
Furnishings, fittings, room contents	101	14
Storage, paper, tissue, tyres, scaffold boards	9	1
Unknown or not easily categorised	140	20
Total	**700**	**100**

4. BACKGROUND TO THE MATERIAL GROUP NUMBER SYSTEM

The Material Group Number System was developed primarily to assess the fire hazard of wall and ceiling surface linings. It replaced the AS 1530 Part 3 (early fire hazard) fire test indices that were previously used in New Zealand. The Group Number methodology has been the subject of significant research in Europe (Sundström & Axelsson, 2002; Sundström, 2007), Australia (FCRC Project 2 – Stage A [Fire Code Reform Centre, 1998]), and more recently in New Zealand (Collier, Whiting & Wade, 2006).

The current methodology applied in the Building Code of Australia (Specification C1.10) was generally adopted in New Zealand in 2012. It uses the ISO 9705 fire test method (ISO, 2009) as a reference scenario, with the time to flashover being the primary parameter of interest. This fire test requires the surface lining material to be installed on the walls and ceiling of a rectangular room with dimensions 3.6 m long x 2.4 m wide x 2.4 m high. An opening with dimensions 2.0 m high x 0.8 m wide is present in one of the short walls. A gas burner is used to expose the wall lining in one of the corner intersections opposite the wall opening. The combustion gases from both the burner and the surface lining materials (if burning) are collected in a hood outside the room. Oxygen calorimetry is then used to determine the rate of heat release and smoke production.

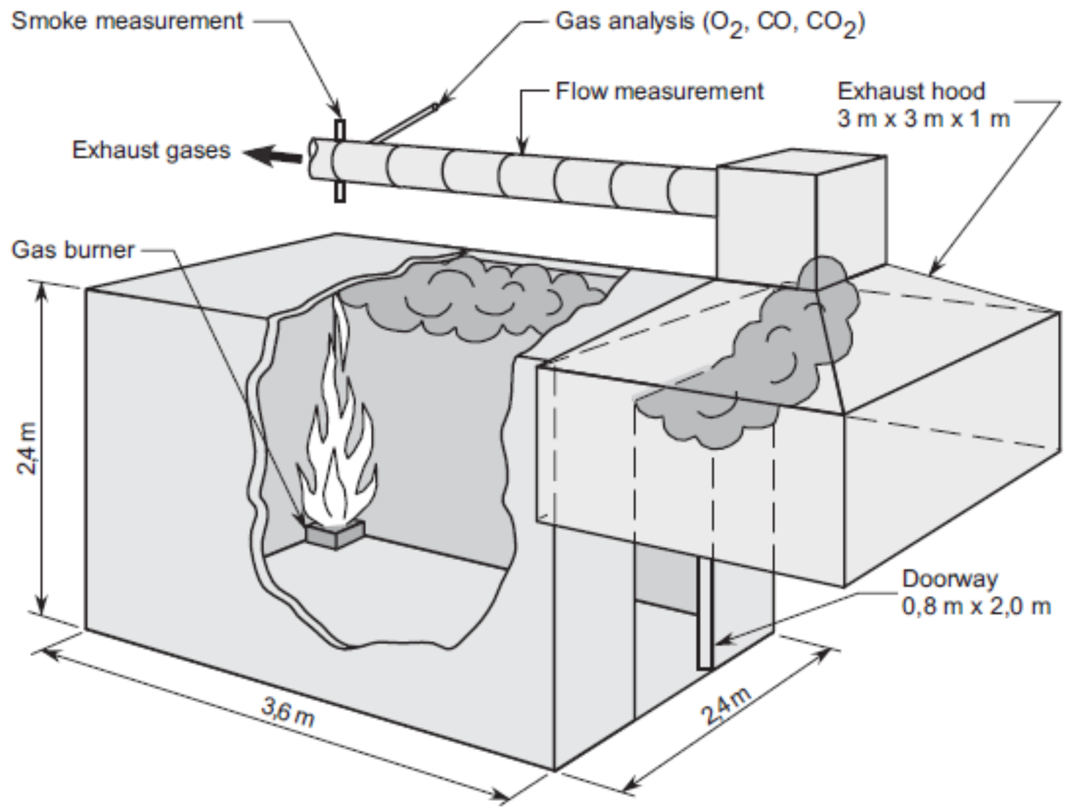


Figure 2 ISO 9705 room fire test for surface linings (extracted from Sundström & Axelsson, 2002)

In the ISO 9705 room fire test, surface linings are exposed to 100 kW for ten minutes and then 300 kW for a further ten minutes. The time to reach flashover (taken as reaching a heat release rate of 1.0 MW in the ISO 9705 room) is then determined. Materials are classified from Group Number 1 (best) to Group Number 4 (worst) based on their measured time to flashover in the fire test.

Although the reference scenario is a full-scale test, most surface linings can be tested using the less expensive smaller-scale ISO 5660 cone calorimeter fire test (ISO, 2012). In this case 100 mm square samples are subjected to an irradiance of 50 kW/m^2 and the time to ignition, rate of heat release and smoke production are measured. The results from this test have been previously correlated (Kokkala, Thomas & Karlsson, 1993) to predict the time to flashover in the full-scale ISO 9705 fire test. This correlation can be used to assign a Group Number for most, but not all, materials. This is because some products are not suitable for testing at small scale using ISO 5660. The correlation was developed and validated for solid homogeneous materials that did not melt or slump.

The fire performance of metal-faced sandwich panels for example, are very dependent on the detailing around the joins in the metal sheet. The small scale of the ISO 5660 test is not able to assess how the mechanical behaviour of the panel connections contributes to their behaviour in fire (Collier & Baker, 2013). In the case of foil-faced combustible insulation products (as typically used for flexible ducts), better but misleading results in the ISO 5660 test may be recorded. This may occur with a combination of a reflective foil surface and a combustible material beneath that tends to shrink/melt away. Furthermore, the highly-reflective foil facing acts as a barrier to the radiant heat in the absence of flame contact. The foil can also assist in retaining the combustible insulation in contact with flame where it can ignite and contribute more to a growing fire event. However, in the presence of flame contact, thin aluminium or metallised foils can easily melt or burn through, exposing the combustible insulation behind to the full amount of radiant heat.

In 2012, the Australian Standard AS/NZS 3837 (based on and very similar to ISO 5660) was amended (Standards Australia, 1998a). The change identified materials and assemblies for which the empirical correlations for predicting Group Numbers had not been validated. It listed the following materials and assemblies where the small-scale test should not be used to determine Group Numbers.

- All assemblies, including those with profiled facings.
- Materials and assemblies that contain materials that melt or shrink away from a flame.
- Assemblies with joints and openings.
- Products with a reflective surface.

Appendix A of C/VM2 describes the detailed procedure for assigning or predicting a material's Group Number. The following is a general indication of the expected performance of some common materials (actual performance is affected by factors such as chemical composition, thickness and additives, so must be verified by test):

- **Group Number 1 materials** – these include non-combustible materials or materials with limited combustibility. Examples are plasterboard and similar materials (usually low hazard) where no flashover is reached in the ISO 9705 test in 20 minutes.
- **Group Number 2 materials** – these include many fire-retardant-treated timbers, where no flashover is reached in the ISO 9705 test in ten minutes.
- **Group Number 3 materials** – these include ordinary timber products and similar materials, where no flashover is reached in the ISO 9705 test in two minutes.
- **Group Number 4 materials** – these include exposed polymeric foams or similar products where flashover is reached in the ISO 9705 test within two minutes. Group Number 4 materials are considered hazardous when installed as room linings and are not acceptable in occupied spaces.

Smoke production

Smoke production is also measured in the ISO 5660 and ISO 9705 fire tests and criteria is set depending on the application. In New Zealand, a product meeting the smoke criteria has an 'S' appended to the Group Number classification, e.g. Group Number 1-S.

The smoke production criteria is a high-threshold secondary control intended only to weed out the very 'bad performers'. Limiting the rate of heat release (which generally follows the mass loss rate for well-ventilated fires) is the primary means of also limiting the overall quantity of smoke produced. This is because of the proportional relationship between mass heat loss and smoke production.

Smoke production is not limited for walls and ceilings in NZBC Clause C3.4a where fire sprinklers are installed. It is also not limited for the external surfaces of ducts and pipe insulation, sprinklers or not.

Why change?

The switch to the Group Number System followed a similar move by Australia to regulate wall and ceiling surface linings some years previously (Fire Code Reform Centre, 1998). Up until that time New Zealand and Australia had both relied on AS 1530.3 as the fire test method for regulating fire properties of wall and ceiling linings. In 2005, the Building Code of Australia (BCA) was amended replacing AS 1530.3 with the Group Number System. This left New Zealand alone in using AS 1530.3 for regulating the fire properties of wall and ceiling linings. This was seen as representing a possible trade barrier and was counter to an expressed desire to utilise international standards whenever possible. This provided further impetus to review the test methods used in New Zealand.

However, Australia did not include duct surface finishes when the change from AS 1530.3 to Group Numbers occurred in 2005. The reason for this is that duct materials were outside the scope of the research at the time. The contribution to fire hazard from duct materials was not considered to be sufficiently high to warrant further attention at that time. See Section 6.1 for discussion of the current Australian requirements.

ISO 5660 and ISO 9705 are recognised international fire test methods. While not currently used extensively throughout the world for regulating the fire properties of wall and ceiling linings, they are accepted as being scientifically appropriate and valid. They provide useful data for fire safety engineering purposes. They are also extensively used in research. ISO 9705 is additionally the so-called 'reference scenario' for the Euroclass Classification System now commonplace throughout Europe (see Section 6.2).

5. NEW ZEALAND REQUIREMENTS FOR DUCT AND PIPE INSULATION

5.1 New Zealand

5.1.1 Household units

The reaction-to-fire properties of duct materials, where they are installed within individual household units, is not regulated due to the limits of application of NZBC Clause C3.4. The limit on application is stated as:

> Clause C3.4 does not apply to *detached dwellings*, within *household units* in *multi-unit dwellings*, or *outbuildings* and *ancillary buildings*.

Therefore, this investigation does not concern itself with the reaction to fire behaviour of duct materials installed within individual household units. As a result, the number of fire incidents associated with duct and pipe insulation previously shown in Figure 1 for single houses (about one-half) is not subjected to regulation by NZBC Clause C3.4a.

5.1.2 Other property types

The relevant performance requirement is given by NZBC Clause C3.4a and summarised as shown in Table 4. This Code Clause did not change in December 2013. Table 4 shows that the internal and external surfaces of ducts for HVAC systems have different requirements. Acoustic treatment and pipe insulation within air handling plenums in sleeping uses require the same performance as the external surfaces of ducts.

A higher level of performance is specified for the internal surfaces of ducts compared to the external surfaces. This reflects the higher risk of fire/smoke being distributed internally through the ducting to other parts of the building in the event of the internal duct surfaces burning.

The smoke production characteristics of duct materials is only regulated for the internal surfaces of ducts and then only in unsprinklered buildings. Fire properties of pipe insulation are subject to control only under a very narrow scope of application i.e. within air handling plenum in sleeping uses. The concern would be the potential for combustion products from burning pipe insulation being distributed elsewhere throughout the building through the air handling system.

In all cases, performance is specified by reference to a material Group Number, explained more fully in Section 4.

Table 4 Requirements applying to duct and pipe insulation extracted from New Zealand Building Code Clause C3.4a (Tizard, 1992)

Area of building	Without fire sprinklers	With fire sprinklers
Internal surfaces of ducts for HVAC systems	Material Group Number 1-S	Material Group Number 1 or 2
External surfaces of ducts for HVAC systems	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3
Acoustic treatment and pipe insulation within air handling plenums in sleeping uses	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3

5.1.3 Previous New Zealand research

Collier (2007) conducted a summary desktop study considering flexible fabrics, ductwork and cables. Based on this, he recommended that the reaction to fire properties of ductwork materials be included in the provisions applying to surface linings. He found that there was little fire experience data in the public literature and also little evidence that duct materials featured significantly in fire incident statistics. Collier proposed they should be treated the same as wall and ceiling linings, as had been done previously.

Collier recommended that the internal and external surfaces of ducts be required to meet Group 1 or Group 3 ratings respectively. He similarly recommended that acoustic treatments and pipe insulation require a Group 3 rating with the testing regime following ISO 9705. This was supported by Swedish research (Sundström, Axelsson & Rohr, 2001; Sundström & Axelsson, 2002).

5.1.4 Requirements for ducts and pipe insulation

It is the practice in many countries to assess the reaction to fire properties of duct materials using the same fire test as for wall and ceiling materials (e.g. European Union countries use the SBI test; North America uses ASTM E84). This was also the approach taken in New Zealand when previously using AS 1530.3 and after the switch to the Group Number System in 2012 when either ISO 5660 or ISO 9705 could be used. Australia now assesses duct materials and surface linings differently as noted above.

5.1.4.1 Requirements, pre-April 2012

Previously, reaction to fire properties of internal and external surfaces of ducts was assessed using the spread of flame (SFI) and smoke developed (SDI) indices of AS 1530.3. This was as specified in the compliance document for the fire safety clauses of the Building Code (DBH, 2005).

Paragraph 6.20.20 and Table 6.2 contained requirements for air ducts serving more than one firecell in Purpose Groups SC, SD, SA, SR, IE, CS, CL and CM. They required surface finishes meeting SFI not >0 and SDI not >3 for the interior surfaces and SFI not >7 and SDI not >5 for the exterior surfaces.

Paragraph 6.9.5 did not permit air ducts passing through exitways to include combustible materials. This is a more stringent requirement than meeting the AS 1530.3 criteria mentioned above.

Paragraph 6.20.21 waived any external surface finish requirements for air ducts contained wholly within a protected shaft (not containing lifts).

AS 4254 was not referenced under the fire safety clauses of the New Zealand Building Code prior to 2012.

Overall, reaction to fire properties for HVAC ducts was less restrictive under the pre-April 2012 regime. In particular the surface finishes were only regulated where the duct served more than one firecell in specified purpose groups as described above (Paragraph 6.20.20).

5.1.4.2 Requirements, April 2012 to December 2013

In the period between April 2012 and December 2013, the Group Number System was in effect as required by Clause C3.4a of the NZBC. It applied equally to wall and ceiling surface linings as well as duct materials.

In the case of a duct material, a Group Number classification was assigned following fire testing to ISO 5660 or ISO 9705. In each case the product was required to be tested in a flat configuration to suit the requirements of the test.

For the reasons given in Section 4, foil-faced polyester-insulated air ducts were not considered appropriate to be tested at small scale using ISO 5660. Instead full-scale room testing to ISO 9705 was carried out by a number of manufacturers.

It should be noted that the same limitations regarding fire testing of foil-faced combustible insulation materials would have applied to testing previously done using the AS 1530.3 fire test. However, it was not recognised previously and there was no alternative test specified in the Building Code.

Limits of application applying to Clause C3.4a mean that the performance criteria do not apply within household units. However, the provision to only control surface finishes of ducts when the HVAC served more than one firecell was not maintained in the new system post-April 2012. This meant that reaction to fire properties of HVAC ducts serving only one firecell in some buildings such as supermarkets, retail and assembly spaces etc, was introduced where previously there had been no requirement.

The Acceptable Solutions C/AS2 to C/AS6 (Paragraph 4.9.5) do not permit air ducts passing through exitways to include combustible materials (as per the pre-April 2012 requirements). This is a higher performance level than would be provided with a Group Number of 1 specified in the Code Clause C3.4a. The Acceptable Solutions C/AS2 to C/AS6 also waive any external surface finish requirements for air ducts contained wholly within a protected shaft (not containing lifts).

5.1.4.3 Requirements, post-December 2013

Changes were included in the December 2013 amendments (MBIE 2013). This allowed the fire hazard properties to be determined by testing to AS 4254 Part 1 or 2 (Standards Australia, 2012a,b) as applicable for flexible and rigid ducts respectively. This provided an alternative means of establishing a Group Number 1-S for ducts.

AS 4254 is a general standard for the manufacture and installation of ductwork for air handling systems. The fire hazard properties specified within the standard are determined using the fire test methods AS 1530.3 and the burning test from UL 181 (factory-made air ducts and connectors). SFI not >0 and SDI not >3 from AS 1530.3 is required as well as a pass in the burning test in UL 181. UL 181 includes three separate fire tests which measure surface burning characteristics, flame penetration and burning (see Section 6.3.3). Only the burning test is required by AS 4254 along with AS 1530.3.

The UL 181 burning test exposes the finished duct samples, in a vertical, horizontal and 45-degree orientation, to a Bunsen burner flame for two 60-second periods. The ducts should not continue to burn progressively after removal of the burner flame and should not drop particles that are capable of igniting cotton.

In the case of flexible ducts, the burning test in UL 181 is carried out with a number of qualifications. They relate to the fuel, Bunsen burner inside diameter, fuel/air mixture, flame height, sample conditioning and ambient conditions in the laboratory as specified in AS 4254.1 (Standards Australia, 2012a).

See Section 6.1.2 for further details regarding the fire performance requirements within AS 4254 Parts 1 and 2.

5.1.4.4 Ducting used as part of a Type 9 fire safety system

In New Zealand, some buildings with air handling systems are required to meet additional requirements affecting how those systems behave following activation of a fire alarm. The additional requirements are triggered by requiring a Type 9 fire safety system.

When a Type 9 system is required it means that the air handling system has to comply with either:

- AS/NZS 1668 Part 1 (Standards Australia, 1998b) and interface with any Type 4 or 7 system installed if it is self-contained detection, control and provision of output signal/alarm, or
- NZ 4512 (Standards New Zealand, 2010) to provide ancillary function output for control of the HVAC system if a Type 4 or 7 alarm system is used as a means of smoke detection.

In the former case it is noted that AS/NZS 1668 Part 1 also requires that any material employed in the construction of ductwork complies with the fire performance requirements of AS 4254.

It also includes additional non-combustible requirements for any ducts forming part of a smoke spill system or ductwork used in (commercial) kitchen hood exhaust systems.

Systems designed in accordance with AS/NZS 1668 Part 1 are expected to maintain a tenable atmosphere within fire-isolated exits to enable occupant evacuation and fire brigade search and rescue operations.

NZ 4512 (fire detection and alarm systems in buildings) does not include any fire performance requirement for duct materials.

5.1.4.5 Scope of application compared to surface linings

It is noted that there is currently an inconsistency in the places where the reaction to fire properties of HVAC duct materials are controlled compared to wall or ceiling surface linings. NZBC Clause 3.4a requires wall and ceiling surfaces to be essentially regulated in ‘occupied spaces’, while no such distinction is made for HVAC ducts. Therefore we have the situation of regulating HVAC duct materials within a separated ceiling space or void, but with no requirement on any surface linings within the same space.

To ensure a more consistent scope of application, only regulating the external surfaces of HVAC ducts in spaces which are considered ‘occupied’ or where the ductwork is ‘exposed to view’ could be warranted. However, it would be prudent to continue to regulate the internal surfaces of HVAC ducts due to their potential role in spreading fire and smoke to other compartments within a firecell.

6. INTERNATIONAL REQUIREMENTS FOR DUCT AND PIPE INSULATION

6.1 Australia

6.1.1 Building Code of Australia

Specification C1.10 of the BCA (ABCB, 2015) requires all surfaces of ductwork in Class 2 to 9 buildings to meet the fire hazard properties given in AS 4254 Part 1 (flexible ductwork) or Part 2 (rigid ductwork). This in turn requires the fire performance to be assessed using AS1530.3 as well as a pass when subjected to the UL181 burning test as described in Section 5.1.4.3.

Class 2 to 9 buildings cover most commercial and multi-unit residential occupancies in Australia.

The New Zealand post-December 2013 requirements as described in Section 5.1.4.3. are in general alignment with these BCA requirements.

Notably, AS 4254 does not require the flame penetration test in UL 181 (see Section 6.3.3).

The National Construction Code Volume 2 (ABCB, 2015) regulates materials of flexible ductwork used for the transfer of products initiating from a heat source that contains a flame. They must comply with the fire hazard properties set out in AS 4254 Parts 1 and 2.

6.1.2 AS 4254 Parts 1 and 2

AS 4254 Part 1 (Standards Australia, 2012a) is for flexible ducts and these may be insulated or uninsulated. Fire testing is conducted on the final assembled product with 300 mm internal diameter. The flexible duct system requires SFI not >0 and SDI not >3 when tested to AS 1530.3. The direction of exposure required is not clear, should the duct be of asymmetrical construction. The final assembled product is also required to pass the burning test in UL 181.

AS 4254 Part 2 (Standards Australia, 2012b) is for rigid ducts. The assembled duct system requires SFI not >0 and SDI not >3 when tested to AS 1530.3. The final assembled product is also required to pass the burning test in UL 181. However, ductwork used in kitchen exhaust systems is required to be constructed from galvanised sheet steel or stainless steel.

In addition, liners for rigid ducts assembled on a duct system requires SFI not >0 and SDI not >3 when tested to AS 1530.3. If bulk insulation is used as a liner, separately it also requires SFI not >0 and SDI not >3 when tested to AS 1530.3. The final assembled product including the duct liner is additionally required to pass the burning test in UL 181.

Bulk insulation materials are often applied to rigid ductwork (e.g. for sound absorption or thermal resistance). In this case both insulation and the final assembled product requires SFI not >0 and SDI not >3 when tested to AS 1530.3. The final assembled product as a 300 mm x 300 mm duct including the insulation is also required to pass the burning test in UL 181. UL 181 includes two other fire tests that are not required by AS 4254. These are discussed in Section 6.3.3.

6.1.3 AS 1530 Part 3 fire test

The test method cited in AS 4254 for measuring the spread of flame and smoke developed indices of ductwork is AS 1530.3 (Standards Australia, 1999) also known as the ‘early fire hazard test’. In this test a specimen measuring 450 mm high x 600 mm wide is vertically-mounted on a mobile platform opposite a vertically-mounted gas-fired radiant panel (see Figure 3). Every 30 seconds the specimen is moved closer to the radiant panel until it either ignites or the 12-minute mark of the 20-minute test is reached, after which no further movement occurs.

The SFI is derived from the rate of increase of radiation emitted by the specimen after ignition. The SDI is derived from the optical density measured in the duct. Both indices range from 0 (best) to ten (worst). Two additional indices (ignitability and heat evolved) are also determined in the test but not used in regulation and not discussed here. The maximum heat flux to which a specimen is exposed during the test is about 20 kW/m^2 and there is no direct flame impingement from an external source during the test.

Despite several studies in Australia, the original basis of the SFI could not be verified. Attempts to relate the optical density of smoke in the test to smoke developed in the early stages of a room corner fire were not very successful (Fire Code Reform Centre, 1998).

The results obtained in the AS 1530.3 test can be very dependent on the specimen mounting details. This particularly affects materials that may melt, shrink or slump, thus removing material away from the region of highest heat flux.

The appropriateness of the test method for assessing reaction to fire properties of combustible (thermoplastic) ductwork insulation is therefore very questionable. The reason for this is as described in Section 4 for the ISO 5660 fire test. The AS 1530.3 fire test includes a radiant heat source and the absence of direct flame contact with the material surfaces. A facing such as aluminium foil, reflects a large proportion of the radiation away. Yet it has a melting point low enough for direct flame contact from a moderate fire source to burn through, exposing the insulation.

Polyester duct insulation is reported in ductwork fabricator literature (Express Sheetmetals, 2015) as achieving: ignitability 0, spread of flame 0, heat evolved 0 and smoke developed 0. This is for polyester insulation described as 25 mm thick and 250gsm rated at R0.6. This is the highest (best) result achievable using the AS 1530.3 test method. It indicates that the test method (given the mounting method used for this product) is unable to discriminate between a combustible polyester and a non-combustible specimen such as sheet metal or concrete.

The AS 1530.3 fire test is no longer available in New Zealand and is unavailable outside of Australia for commercial testing. Other countries do not adopt the test method for the regulation of wall/ceiling linings.

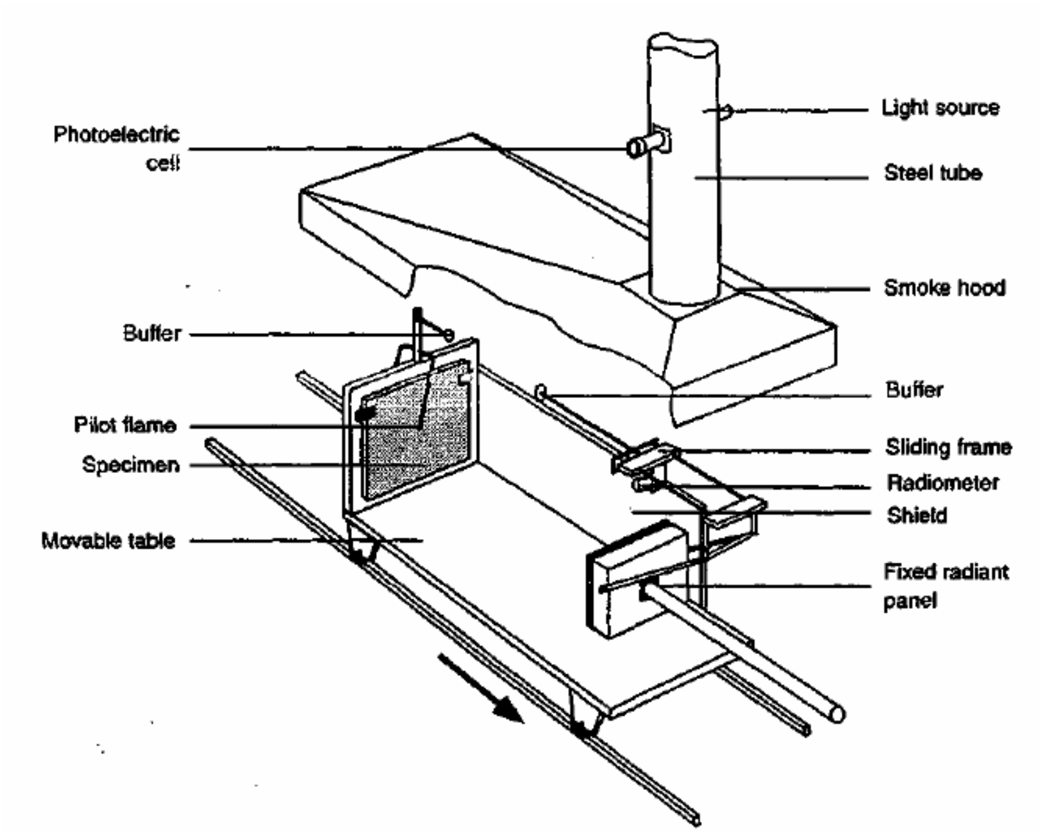


Figure 3 AS 1530.3 – early fire hazard test (extracted from Fire Code Reform Centre, 1998)

6.2 Europe

6.2.1 European reaction to fire classification system

Harmonised fire test methods and classes of performance have been developed for reaction to fire and adopted by member states of the European Union (EU). While the classification system is the same, different countries are free to set their own national requirements. Some countries operate a dual system where existing national requirements (and test methods) are mapped to a corresponding Euroclass, so either can be used.

The European classification system according to EN 13501-1 (CEN, 2007) establishes seven main classes (A1, A2, B, C, D, E and F). It has three sub-classes for smoke development (s1, s2 and s3) and three sub-classes for the formation of flaming droplets/particles (d0, d1 and d2).

In general, four different test methods are used to determine these classes for construction products including linear tube for thermal insulation but excluding floor coverings:

- **EN ISO 1182** reaction to fire tests for building products – non-combustibility test (CEN, 2010a). Requires 12 cylindrical samples (diameter 45 mm, height 50 mm). The sample is located inside a furnace at 750°C. Temperatures are measured continuously during the test. Mass loss of the sample is calculated after the test. These parameters are used to determine and classify the sample as non-combustible or not.

- **EN ISO 1716** reaction to fire tests for building products – determination of the heat of combustion (CEN, 2010b). The material sample is completely combusted under constant volume and in an oxygen atmosphere inside a high-pressure bomb calorimeter. The combusting sample heats up water and temperature rise gives a measurement of calorific potential.
- **EN 13823** reaction to fire tests for building products – building products excluding floorings exposed to the thermal attack by a single burning item (see Figure 4) (CEN, 2002). An intermediate scale test where wall sections are mounted in a right angle to create a corner. A gas burner, located in the corner, produces a heat release rate of 30 kW for 21 minutes. The combustion gases are collected in a hood where heat release rate and smoke production are measured.
- **EN ISO 11925-2** reaction to fire tests – ignitability of building products subjected to direct impingement of flame, Part 2 single-flame source test (CEN, 2010c). The test simulates a small flame impinging the edge or surface of the specimen for a short period (15 or 30 seconds). The time to ignition and the time for the flame to spread upward and reach 150 mm above the application point are recorded.

Figure 4 EN 13823 (single burning item) – test apparatus (Fire Testing Technology, 2015)

The main classes are assigned according to the results of specific tests as follows:

- Class A1 – EN ISO 1182 and EN ISO 1716.
- Class A2 – EN ISO 1182 or EN ISO 1716 and EN 13823 (SBI).
- Class B, C and D – EN 13823 (SBI) and EN ISO 11925-2.
- Class E – EN ISO 11925-2.
- Class F – fire behaviour not determined.

The classifications for smoke production are:

- s3 – no limitation of smoke production required.
- s2 – the total smoke production as well as the ratio of increase in smoke production are limited.

- s1 – more stringent criteria than s2 is specified.

Another parameter considered in the European reaction to fire classification system is the production of flaming droplets and/or particles. The effect of the droplets or particles is considered important, not only for occupant safety, but also to limit the fire spread due to their falling onto combustible furniture.

The classifications for flaming droplets/particles based behaviour in the EN 13823 test are:

- d2 – no limitation, i.e. flaming droplets/particles are acceptable.
- d1 – no flaming droplets/particles persisting longer than ten seconds within 600 seconds from ignition.
- d0 – no flaming droplets/particles are allowed within 600 seconds from ignition.

Not all EU countries regulate the production of smoke or flaming droplets. Very few member states introduced new requirements for smoke or burning droplets when they adopted the Euroclasses if previously there had been no existing national requirement for them (BRE, 2005b).

A more detailed description of the classification criteria for each fire test is given in 0. Example Euroclasses (A1, A2) for glass wool thermal external insulation for metal ducts is shown in Table 5.

Table 5 Example Euroclasses for glass wool external insulation for metal ducts (Isover, 2015)

Product description	Reaction to fire (Euroclass)	Thermal conductivity (at 10°C in mW/m.K)	Key benefits	Product name*
Glasswool blanket with aluminium facing**	A1	32	Thermal insulation with easy installation	CLIMCOVER Roll Alu1
Glasswool blanket with aluminium facing	A2,s1-d0	35	Thermal insulation, needs additional mechanical fixing	CLIMCOVER Roll Alu2
Glasswool lamella mats with aluminium facing	A2-s1,d0	37	Thermal insulation with enhanced mechanical strength	CLIMCOVER Lamella
Glass wool tube with aluminim facing	A2-s1,d0	36	Thermal insulation with easy installation	CLIMCOVER Tube Alu2***

Euroclass B, C and D are approximately equivalent to Group 1, 2 and 3 respectively under the reaction to fire system used in New Zealand and Australia. This is based on expected performance in the full-scale ISO 9705 fire test. Wall and ceiling linings with a certified Euroclass performance may be used in New Zealand on this basis (MBIE, 2015).

Also of particular interest to this study are separate Euroclasses for linear pipe thermal insulation products where the Euroclass rating has the subscript ‘L’ following the main Euroclass. This is shown in Figure 5. Further discussion and background to the development of the linear pipe thermal insulation criteria is given in Section 8.

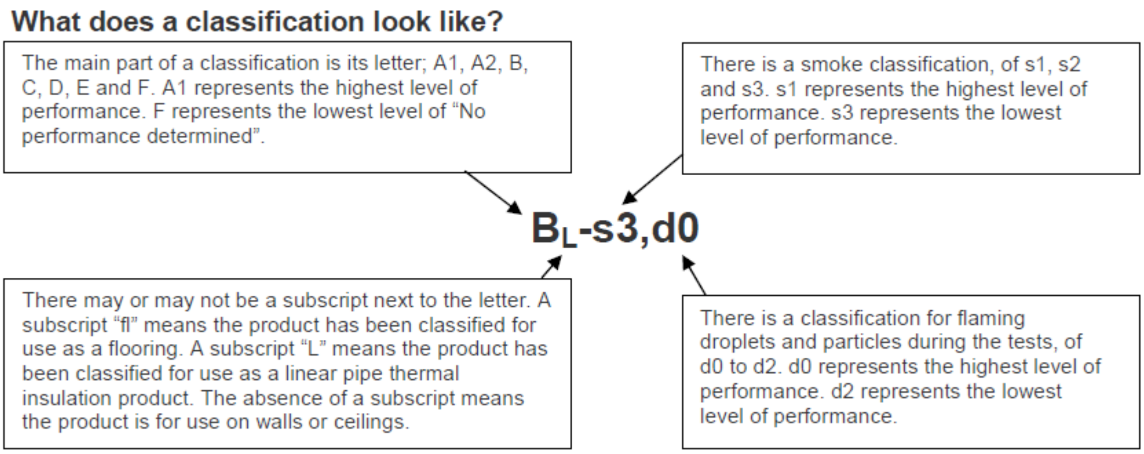


Figure 5 European classification example for a linear pipe thermal insulation product (extracted from Chiltern International Fire, undated)

6.2.2 Background to the Euroclass classification system

Sundström (2007) described in detail the development of the European fire classification system for building products and the use of a classification parameter called '**Fi**re **G**rowth **Ra**te' (FIGRA). FIGRA is defined as the growth rate of the burning intensity and is calculated as shown in Figure 6. The relationship between occurrence of flashover in the room corner test taken as reaching a heat release rate of 1 MW and the FIGRA is illustrated in Figure 7.

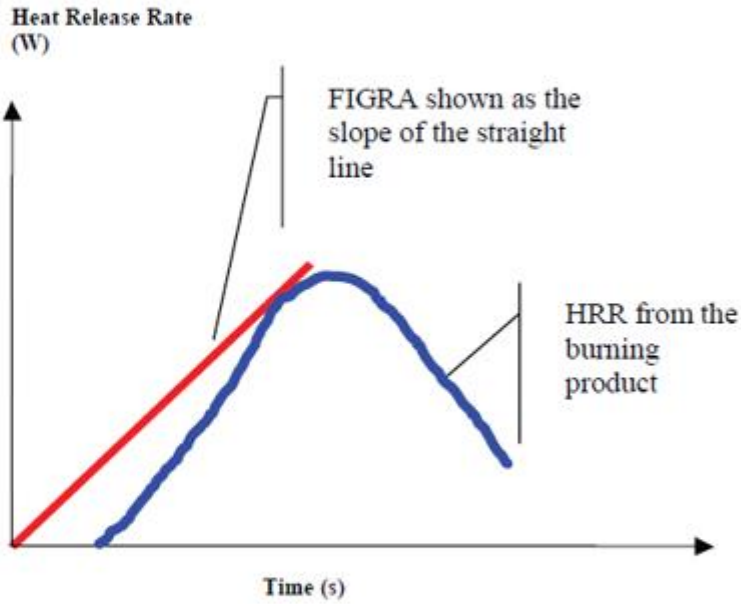


Figure 6 FIGRA is the maximum value of the function (heat release rate/elapsed test time); shown as the slope of the straight line (extracted from Sundström, 2007)

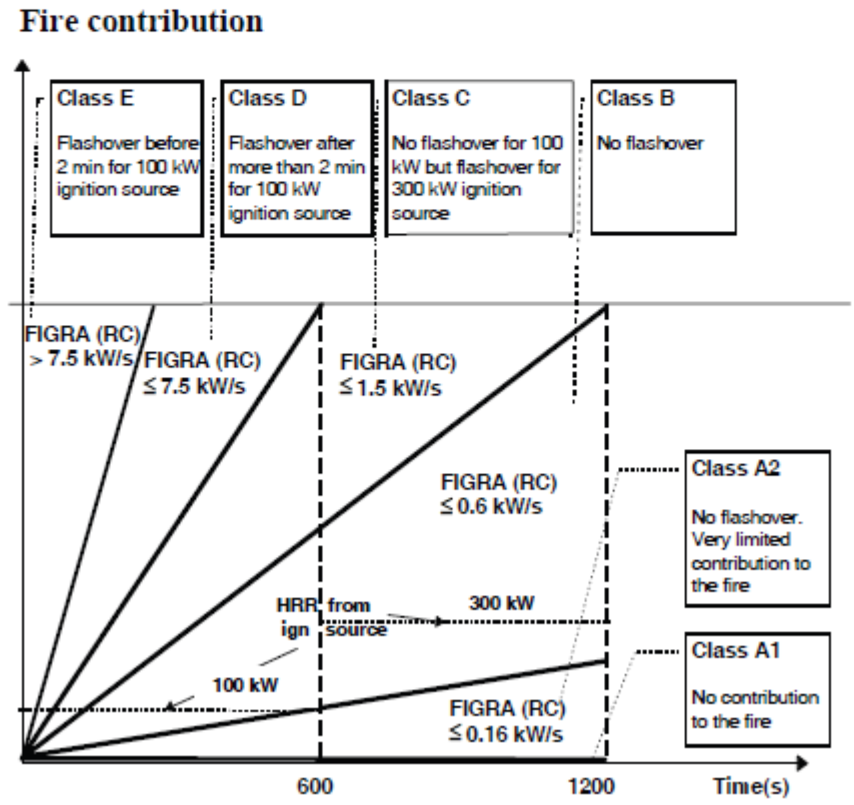


Figure 7 The value of FIGRA for surface linings and the occurrence of flashover in the ISO 9705 room test (extracted from Sundström, 2007)

6.2.3 England and Wales

Approved Document B of the Building Regulations – Fire Safety (Department for Communities and Local Government, 2006) refers to BS 5588 Part 9 (British Standards Institution, 1999). BS 5588 Part 9 covers non-combustible building service ducts and ductwork manufactured from metal and/or rigid mineral-based components. It does not cover ductwork manufactured from materials that rapidly melt, shatter or degrade during fire exposure, for example glass and plastic materials.

BS 9999:2008 (British Standards Institution, 2008) is a guidance document that sits between Approved Document B and fire engineering solutions. It is intended to replace the BS 5588 series of documents (The Fire Strategy Company, 2009). BS 9999 requires insulation applied as an internal lining to ductwork to achieve either Class 0 (national) or Class B-s3, d2 (European) and be either a non-combustible material or material of limited combustibility.

In the European system a material of limited combustibility is any material/product classified as Class A2-s3, d2 or better in accordance with EN 13501-1:2007 (CEN, 2007). Alternative criteria is also given in Table A1.7 of Approved Document B based on national classes.

External insulation situated within a fire-resisting ductwork enclosure requires Class 0 (national) or Class B-s3, d2 (European) unless the enclosure is subdivided at each floor level.

External insulation not situated within a fire-resisting ductwork enclosure is required to have a surface spread of flame rating not less than that for the wall or ceiling which the ductwork traverses. This applies when the insulation is situated within 500 mm of a fire damper.

BS 9999 also provides requirements for flexible joints and flexible connectors. Flexible joints and connectors are required to be either:

a) Non-combustible materials, materials conforming to Euroclass A1; or

b) Materials which when tested to BS476-6 have a fire propagation index (I) of not more than 12 and a sub-index (i1) of not more than 6 and are situated at least 1 metre from any fire damper.

Based on the above, it can be observed that BS 9999 places more emphasis on the reaction to fire performance of insulation applied as an internal lining to ductwork, compared to external insulation.

A study was commissioned by the ODPM Building Regulations Division to determine if requirements for stricter control of smoke and flaming droplets for wall and ceiling linings in Approved Document B could be justified on life safety grounds (BRE, 2005b). The study noted that flaming droplets tended to be material-based properties and that Approved Document B already had controls on the permissible area of thermoplastics in ceilings. Therefore more stringent general requirements for flaming droplets were thought probably unnecessary. It concluded that there would be no significant benefit in introducing more stringent classifications for smoke and flaming droplets and/or particles for wall and ceiling linings in Approved Document B.

6.2.4 Equivalencies in other European countries

Table 6 shows the Euroclass performance corresponding to national reaction to fire classifications for England and Wales, Germany, France, Sweden, Italy and Netherlands.

Table 6 Equivalence in reaction to fire performance classification in Europe (extracted from Association of Ductwork Contractors & Allied Services, undated)

Euroclass In accordance with EN 13501-1 + A1:2009	UK (England and Wales)	Germany	France	Sweden	Italy	Netherlands
A1	Non-combustible	A1	Non-combustible	A1 (Non-combustible prior to 1st Jan 2012)	Class 0	Non-combustible
A2	Material of limited combustibility	A2	M0 or M1	A2 (Material of limited combustibility prior to 1st Jan 2012)	Class 1 or Class 2	
B	Class 0 [4]	B1	M1	B (Class 1 surface lining prior to 1st Jan 2012)	Class 1 or Class 2	Class 1 or Class 2
C	Class 1 [5]	B1	M2	C (Class 2 surface lining prior to 1st Jan 2012)	Class 2 or Class 3	Class 3
D	Class 3	B2	M3	D (Class 1 surface lining prior to 1st Jan 2012)	Class 3	Class 4
E		B2	M4	E		
F		B3		F		

3. It is important to note that the national classifications for reaction-to-fire do not automatically equate with European reaction-to-fire classifications or with each other. This is because the methodologies and measurements used in the national tests differ from those employed in the tests associated with harmonised European tests. Products cannot assume a European class for reaction-to-fire performance unless they have been tested using a European testing standard.

4. Class 0 products are: a) Composed throughout of materials of limited combustibility or b) Products with Class 1 performance for surface spread of flame when tested in accordance with BS 476-7 which, when tested in accordance with BS 476-6, also have a fire propagation index (I) of not more than 12 and a sub-index (i1) of not more than 6

5. Class 1 or Class 3 is achieved when a material or product meets specific criteria for lateral spread of flame in accordance with BS 476-7.

New building regulations were adopted in Sweden in 2012 and these replaced the old national classes for Euroclasses based on EN 13501-1. In Sweden, in addition to that shown in Table 6 for the main Euroclasses, pipe insulation requires B_L-s1,d0 (SP Technical Research Institute of Sweden, 2015).

Section E7 of the National Building Code of Finland is concerned with the fire safety of ventilation installations. The aim is to prevent fire spread from one compartment to another via ventilation ducts. The minimum reaction to fire requirement is usually A2-s1, d0 using the European classification system (Association of Ductwork Contractors & Allied Services, undated).

6.3 North America

6.3.1 CAN.ULC-S110 – Standard Methods of Test for Air Ducts

In Canada, CAN/ULC-S110-13 – Standard Methods of Test for Air Ducts (ULC Standards, 2013), is the relevant air ducts test standard. The requirements apply to materials for the fabrication of air duct systems. It includes preformed lengths of flexible or rigid ducts, materials in the form of boards for field fabrication of rigid ducts and preformed flexible connectors.

Materials of ducts and connectors require fire testing to determine surface burning characteristics using CAN/ULC-S102 (ULC Standards, 2010). Circular duct materials are required to be cut longitudinally and flattened for testing.

Ductwork-used materials are evaluated with respect to CAN/ULC-S102. This test is similar to the ASTM E84 'tunnel test' (ASTM, 2015) but the results that are recorded and declared are completely different than ASTM E84.

A flame resistance test is additionally required using CAN/ULC-S109 (ULC Standards, 2003).

A flame penetration test is also required as described in CAN/ULC-S110-13 (ULC Standards, 2013).

Ducts and connectors are not permitted to burn progressively, and exterior surfaces of the material are not permitted to drop particles capable of igniting untreated cotton.

6.3.2 FM 4924 – Approval Standard for Pipe and Duct Insulation

FM Approvals Ltd has published an approval standard for pipe and duct insulation (FM Approvals Ltd, 2013). The standard applies to materials to be used as insulation on the exterior of non-combustible pipes or ducts.

The standard requires a room fire test to ISO 9705 or UBC 26-3 with sheet insulation installed on the walls only. For the ISO 9705 test, the insulation must not:

- Burn on the floor of the test enclosure for more than ten seconds.
- Generate an instantaneous total heat flux of more than 20 kW/m² as measured by a heat flux gauge at the centre of the floor.
- Support a propagating fire that extends to the outer extremities of the test area or exits the enclosure door during the 20-minute test duration.

Sheet insulation meeting the second and third bullet-points, may or may not meet the Group 1 criteria under NZBC Clause C3.4. This is because installing the material on the wall surfaces is less onerous and makes the comparison more difficult. Flexible ducting of the type commonly used in New Zealand is unlikely to pass the first bullet-point.

In addition, FM 4924 requires a pipe chase test to demonstrate that tube insulation will not support a self-propagating fire to the end of a 7.3 m horizontal segment of insulated pipe within ten minutes of ignition.

The standard also requires the results of the ASTM E84 test to be reported. However, it places no limits on the values obtained, noting that it is only required to satisfy Building Code requirements.

The FM 4924 room fire testing does not require any calorimetry measurement (reducing cost), only requiring measurement of heat flux at the floor and a series of visual observations. Omitting the material from the ceiling emphasises the lateral flame spread behaviour of the material rather than the upward flame spread implicit within the Group Number System.

6.3.3 Underwriters Laboratories UL 181

UL 181 (Underwriters Laboratories, 2013b) applies to materials used for the fabrication of air ducts and connectors. It includes preformed lengths of flexible or rigid ducts, boards used in field fabrication of rigid ducts and preformed flexible air connectors.

Air ducts and air connectors are classified as:

- Class 0, when having surface burning characteristics of zero.
- Class 1, when having a flame spread index not greater than 25, without evidence of continued progressive combustion, and a smoke developed index not exceeding 50.

Surface burning characteristics are measured using UL 723 (Underwriters Laboratories, 2013c) with the Steiner Tunnel apparatus. This is also the same as the ASTM E84 test used for evaluating surface burning characteristics of interior wall finish materials (ASTM, 2015).

A flame penetration test is required by UL 181 that exposes the exterior surface of the duct to a gas flame from a furnace. It must resist penetration from the flame for a period of 30 minutes while supporting a concentrated load.

A burning test is also undertaken where duct sections are mounted in horizontal, vertical and inclined orientation and exposed to a flame from a Bunsen burner for two 60-second periods. There should be no flaming or glowing after the burner is removed (i.e. no continued progressive combustion) and there should be no droplets of burning material capable of igniting a layer of cotton.

7. PRODUCTS USED IN NEW ZEALAND

7.1 HVAC ducts

7.1.1 Method

A small number of product manufacturers/suppliers were approached by the research team to gather information about the materials commonly used for HVAC ducts. The companies approached consisted of:

- One base material manufacturer, i.e. a company that manufactures the component materials.
- Two fabricators, i.e. companies that purchase the components and then assemble them into finished ductwork.

The survey did not include any contractors, i.e. companies that install ductwork and duct materials on site.

For completeness it should additionally be noted that base material manufacturers can also supply finished materials to contractors for installation on site, without any fabrication being involved.

Each company was asked a standard series of questions relating to the types of materials used in both flexible and rigid ducting applications, as well as the configuration and usage of materials.

Information was gathered in a range of different ways:

- Face-to-face interviews.
- Email surveys.
- Telephone interviews.
- Technical literature.
- Websites.
- Standards.
- Mechanical services drawings for actual building projects.

Generically there are two types of ductwork that are relevant to this study; namely, flexible ducting and rigid ducting.

7.1.2 Flexible ducting

Flexible ducting is commonly used to connect supply air diffuser outlets to rigid ductwork in HVAC systems. Because the pressure losses are greater in flexible ducting, short runs are preferred along with minimal changes in direction. Typically, duct lengths supplied are 3 to 6 m.

Generically, flexible ducting is typically circular in cross-section and can either consist of an uninsulated sleeve or alternatively a 'sandwich' construction that has an inner lining, core insulation and an outer sleeve.

The sleeves can either be plastic or aluminium foil with the inner and outer sleeves being in any combination. The plastic sleeves can also be metallised and either the plastic or aluminium foil sleeves can be reinforced and have multiple layers laminated together.

Duct diameters (nominal internal) range from 100 to 550 mm, with the most commonly used sizes being 150, 200, 250 and 300 mm. Duct diameters less than 150 mm are generally used in residential occupancies only, e.g. apartments, and are typically uninsulated.

Flexible ducting can either be in a wire or interlocking form, with approximately 70% of the flexible ducting manufactured in New Zealand being wire and 30% interlocking. The interlocking ducting type is used exclusively in commercial applications, while the wire ducting is used in approximately equal proportion in residential and commercial situations.

Wire ducting has a spring steel wire helix bonded into a spirally-wound inner sleeve and is the more flexible of the two. This product can also be compressed longitudinally down to approximately one-tenth of its original length, but will 'spring' back into its original length when released.

Interlocking ducting is semi-rigid and is formed using spirally-wound aluminium foil strip that is corrugated and mechanically locked at the spiral edges, with the corrugated profile providing self-support. The inner sleeve is typically the corrugated aluminium strip, while the outer sleeve can be any other of the generic outer sleeve options, albeit typically plastic.

The insulation material is generally lofted polyester blanket. The vast majority of flexible duct insulation in the New Zealand market is 25 mm thick with a thermal resistance of R0.6. However, it is expected that usage of the 50 mm thick R1.0 grade will increase as more emphasis is placed on energy efficiency. The 25 mm R0.6 grade has a typical weight of 250 g/m^2, which equates to a nominal density of 10 kg/m^3. Greater thermal efficiency can be achieved by thicker and/or denser insulation.

It is observed that polyester insulation for flexible ductwork is very common in New Zealand and Australia. They are relatively uncommon in Europe and North America where glass fibre or mineral fibre ductwork insulation products are preferred/required. This could be due to polyester insulation not being capable of meeting the fire performance requirements in many countries.

7.1.3 Rigid ducting

Rigid ducting is generally the primary part of the reticulation network, while short lengths of flexible ducting form the secondary distribution elements of the system that supply air to individual outlet diffusers.

Rigid ducting typically consists of traditional sheet metal ducts that can then be insulated either internally or externally with thermal and/or acoustic insulation materials.

Rigid ducting can also consist of self-supporting sandwich materials with foamed plastic cores, as well as rigid polyester. Another class of material used as rigid ducting is rigid plastic piping.

Rigid ducting is generally larger than flexible ducting and is usually more heavily insulated.

The insulation material for rigid ducting can consist of a range of materials such as polyester, mineral wool and foamed plastics, and can be in itself rigid, semi-rigid or flexible. The insulation can also have a facing material on one or both faces, depending on the application, and can consist of materials such as plastic, fabric and foil.

To give a comparison with flexible duct insulation, typical rigid ducting polyester insulation would be 25 mm thick and 875 g/m^2 or 50 mm thick and 1750 g/m^2, which equates to 35 kg/m^3. This is 3.5 times denser than the insulation typically associated with flexible ducting. Even denser polyester insulation can be used for rigid ducting, being 100 mm thick and 4800 g/m^2, which equates to a density of 48 kg/m^3.

7.2 Pipe insulation

Pipe insulation is typically used for the following thermal and acoustic reasons:

- Stop condensation (and hence stop rust) on pipe surface.
- Stop pipes from freezing.
- Save energy.
- Protect against extreme temperatures (e.g. to stop people touching extreme temperatures).
- Dampen sound from pipes with acoustic insulation.

The most common applications for pipe insulation in New Zealand are for HVAC in commercial buildings, pipelines in manufacturing processes and personal protection in the industrial sector.

Pipe insulation comes in a wide range of materials and sizes, and is usually supplied either in pre-fabricated sections, as a flexible wrap or less commonly as spray-applied foam (e.g. polyurethane).

7.2.1 Pre-fabricated pipe insulation

Pre-fabricated lengths of tubular insulation are generally used for standard pipe sizes less than 150 mm outside diameter, although some products can be purchased in custom dimensions. The advantage of using pre-fabricated insulation is the ease and speed of installation. Common materials for these are closed-cell elastomeric foam, fibreglass/resin and mineral wool. Less commonly used materials are polyurethane, phenolic foam, rigid polyisocyanurate insulation (PIR), expanded polystyrene (EPS) and cellular glass insulation.

Typical geometries supplied include straights, T-junctions and elbows with more complex geometries available on request. Straights are typically supplied in 1 to 2 m lengths and are sometimes made as one solid piece that slides over the pipe for installation, particularly with closed-cell elastomeric foam. However, more commonly, pre-formed insulation sections are supplied as one piece with a slit down the axial length. Alternatively they are supplied as two separate halves that fit together allowing for the insulation to be easily installed on in-situ pipework. A range of tapes and glues are available for sealing along the seams of the insulation. Flexible foil liners may also be used over the surface of the insulation to act as a vapour barrier and provide protection from UV light and water.

7.2.2 Flexible wrap pipe insulation

Flexible wrap for pipe insulation is most commonly used for large pipe diameters, typically pipes above 150 mm outside diameter. Common materials used here are closed-cell elastomeric foam, fibreglass/resin laminated to foil, mineral wool and ceramic fibre blanket. Again, flexible foil liners are often used over the surface of the insulation to act as a vapour barrier and provide protection from UV light and water.

8. PIPE INSULATION RESEARCH

8.1.1 Swedish research

In 2002, a Swedish study (Sundström, Axelsson & Rohr, 2001; Sundström & Axelsson, 2002) investigating the reaction to fire behaviour of pipe insulation was published. It was motivated by the difficulty in testing linear products (i.e. those supplied in lengths but with cylindrical surfaces such as pipe insulation, ducts and cables) in their end-use condition in a fully satisfactory way. The surface area of pipe insulation in a room would typically be less than the surface area of surface linings in the room.

The study ultimately led to the development of the international fire test standard ISO 20632 (ISO, 2009) (see Section 8.1.2). The test standard was intended to assess the fire performance of a pipe insulation product, supported on a steel pipe, under controlled test conditions.

The research focused on pipe insulation and compared the behaviour of different types in two thicknesses (25 and 50 mm) when installed as a linear product within a small room and exposed to flames from a gas burner.

Three different versions of mounting the pipework were investigated. They used lengths of 90 m, 180 m and 190 m. These represented surface areas of 65%, 130% and 140% compared with the surface area that would be exposed in the same room with the walls and ceiling covered with a sheet material. The majority of the pipework was at a height above the soffit of the doorway (2 m) and was therefore exposed to more severe conditions due to being in the upper hot gas layer. The mounting arrangement adopted for the pipework is shown in Figure 8.

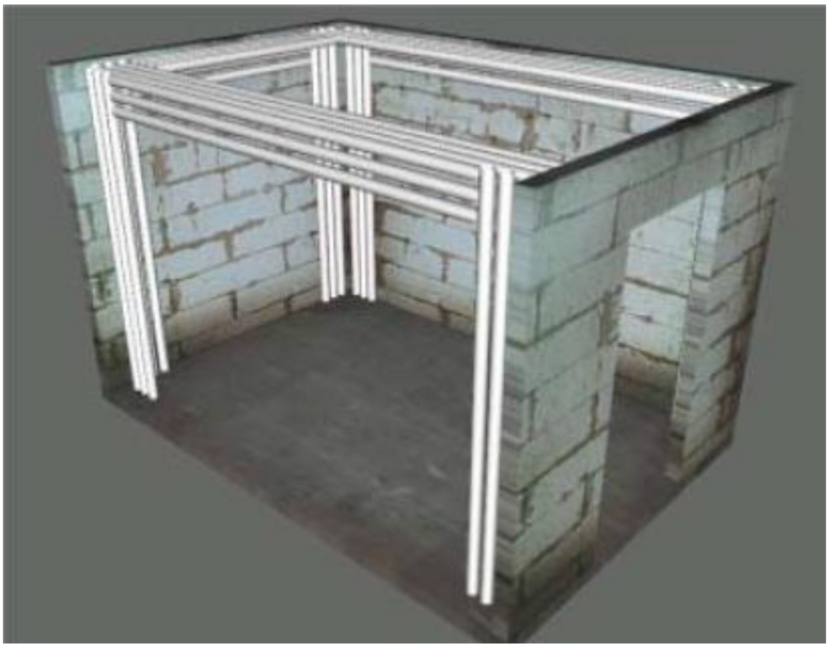


Figure 8 Schematic view of pipework in ISO 9705 room. Roof and left wall removed for better view (extracted from Sundström & Axelsson, 2002)

The overall study analysed more than 25 large-scale room tests and more than 50 SBI tests. Pipe insulation materials from the following product groups were included:

- Flexible polyurethane foam.
- Mineral wool.
- Flexible elastomeric foam.
- Cellular glass.
- Melamine foam.
- Extruded polystyrene foam.
- Polyurethane/isocyanurate foam.
- Semi-rigid polyurethane.
- Flax material.
- Jacketing products of PVC.

When wall and ceiling linings are tested in a small room (ISO, 9705), the phenomenon of flashover due to the fire growth of the surface lining is used a means of assigning a reaction to fire classification for the lining. Because in reality, pipe insulation would be installed in addition to surface linings, a flashover resulting from the insulated pipe materials alone would represent a considerable hazard. Fire growth due to burning pipe insulation is largely determined by the flame spread along the lengths of pipework.

Sundström et al (Sundström, Axelsson & Rohr, 2001) therefore argued that more stringent criteria would be needed for any possible Euroclass for pipe insulation. They developed a correlation between the room fire test and the SBI test using the FIGRA parameter as defined in the SBI. The FIGRA allowed a continuous measure of the fire growth rate as was seen as a more appropriate way of selecting a classification for these types of products. They also analysed the smoke production using the SMOGRA parameter (using the maximum of the function smoke production rate/time).

The correlation between the FIGRA in the room/corner test and in the SBI is shown in Figure 9, and for the SMOGRA as shown in Figure 10.

Some of the conclusions from this research were:

- For fire classification purposes, pipework could be tested using ISO 9705 (ISO, 1993) or EN 13823 (CEN, 2002).
- ISO 9705 could be used as a reference scenario for the burning behaviour of pipework with products mounted as described in the report.
- Testing products in sheet form gives lower fire load, less stable results and does not allow the same level of performance differentiation as for the tube test.
- The results of tests ISO 9705 and EN 13823 correlate equally well for pipework as for wall/ceiling linings.

The rate of heat release versus time for a range of pipe insulation materials tested in the room in the configuration shown in Figure 8 are presented in 0.

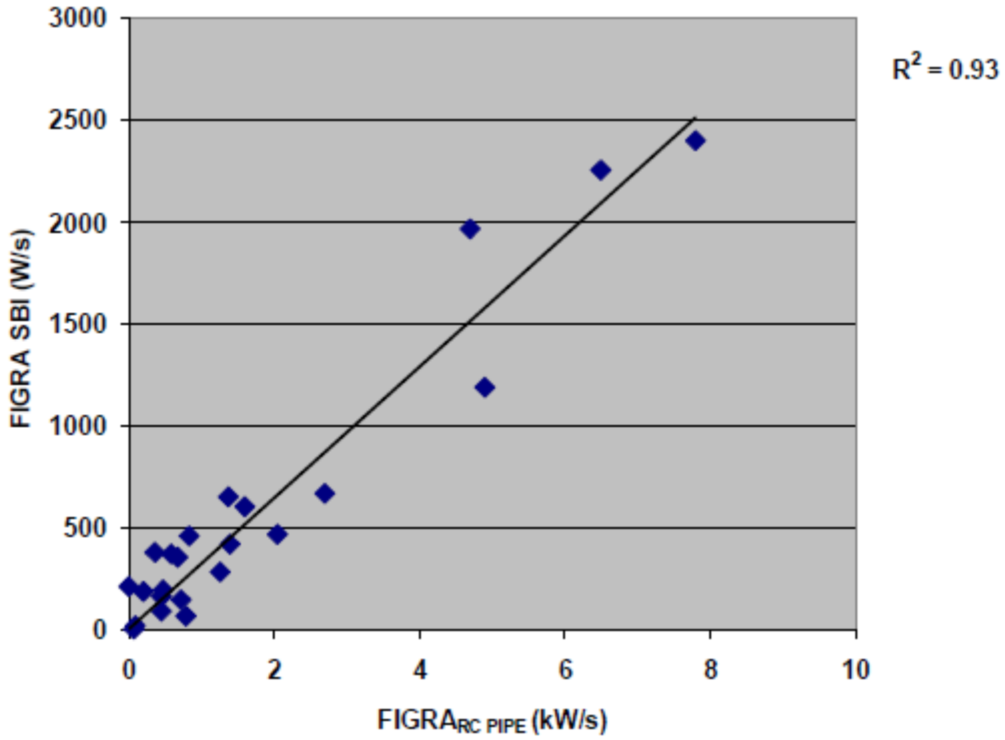


Figure 9 Correlation between the room/corner test and the SBI for FIGRA defined as for the SBI tests (extracted from Sundström & Axelsson, 2002)

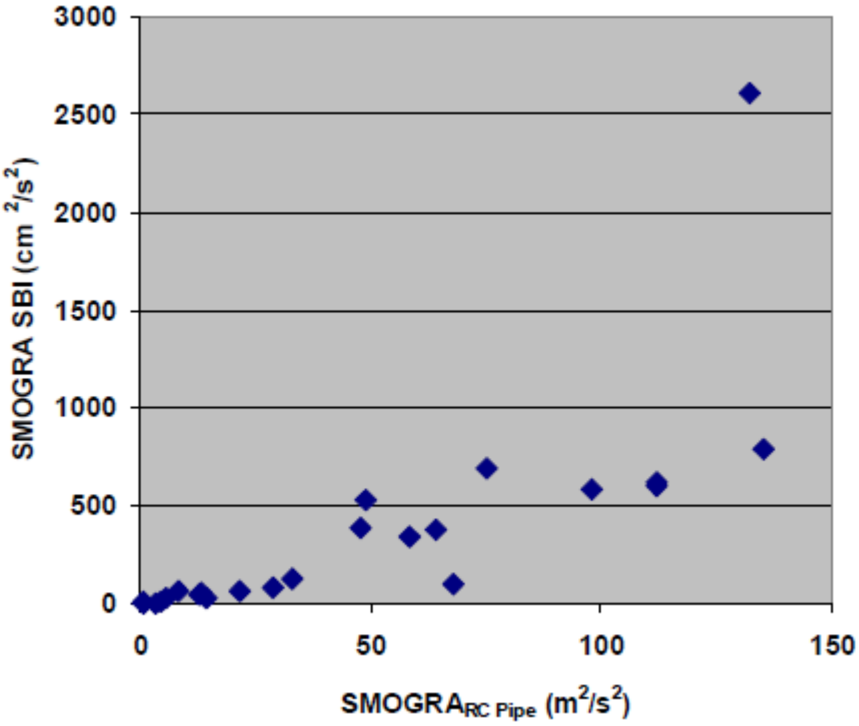


Figure 10 Correlation between the room/corner test $SMOGRA_{RC\ Pipe}$ and the $SMOGRA_{SBI}$ (extracted from Sundström & Axelsson, 2002)

8.1.2 ISO 20632 – Fire test for pipe insulation

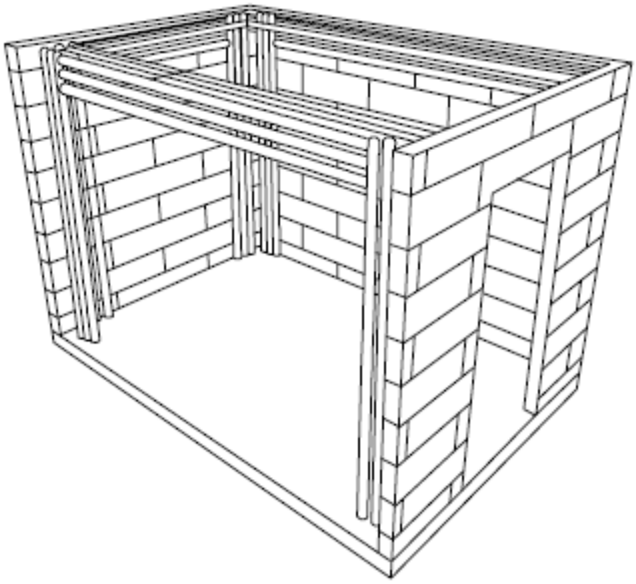
The Swedish research led to the development of an International Standard ISO 20632 (ISO, 2009). ISO 20632 specifies a test method for determining the reaction to fire performance of pipe insulation products and some pipe insulation systems installed in a small room. The scenario would be particularly suitable for pipe and duct rooms in public buildings, apartment blocks and hospitals etc. The standard states that the method is not suitable for pipe insulation in concealed spaces. The test is designed for pipe insulation supported on steel pipes.

The method is intended to assess the following hazards:

- The potential for fire growth along the lines of pipe in the room by measuring the rate of heat release.
- The potential for sustained fire and subsequent spread by measuring the total heat release.
- The potential to reach flashover and spread outside the room.
- The reduction in visibility by measuring optical density of light obscuring smoke.
- The potential of discontinuous fire spread by observation of burning droplets or particles.

The test room dimensions, materials and doorway size, and position are as used in ISO 9705. A schematic, including steel pipe, is shown in Figure 11. The pipe insulation is mounted and fixed on steel pipes having an outside diameter of 21.3 ± 0.1 mm and a thickness of 2.55 ± 0.05 mm. The pipe insulation is tested with an inner diameter of 22.0 ± 0.5 mm and an insulation thickness of between 25 mm and 50 mm.

The ignition source is a 17 cm square propane gas burner positioned in the corner of the room and in contact with the test specimen. The burner output is 100 kW for the first ten minutes and then 300 kW for the next ten minutes.



NOTE The roof and left wall of the room corner have been removed for better view.

Figure 11 Test enclosure used in ISO 20632 showing internal arrangement of pipes

8.1.3 Euroclasses for linear pipe insulation products

As a result of the Swedish research (Sundström, Axelsson & Rohr, 2001; Sundström & Axelsson, 2002) new Euroclass criteria was introduced in 2003 for linear pipe insulation products (*COMMISSION DECISION of 26 August 2003 amending Decision 2000/147/EC implementing Council Directive 89/106/EEC as regards the classification of the reaction-to-fire performance of construction products*, 2003). Pipe insulation, when tested in EN 13823 (SBI test), is mounted as a tubular product as shown in Figure 12 instead of as a flat sheet for a wall or ceiling lining. The FIGRA criteria determined the Euroclass classification is lower (more stringent) for pipe insulation than for the equivalent flat sheet material and is included in Appendix M.

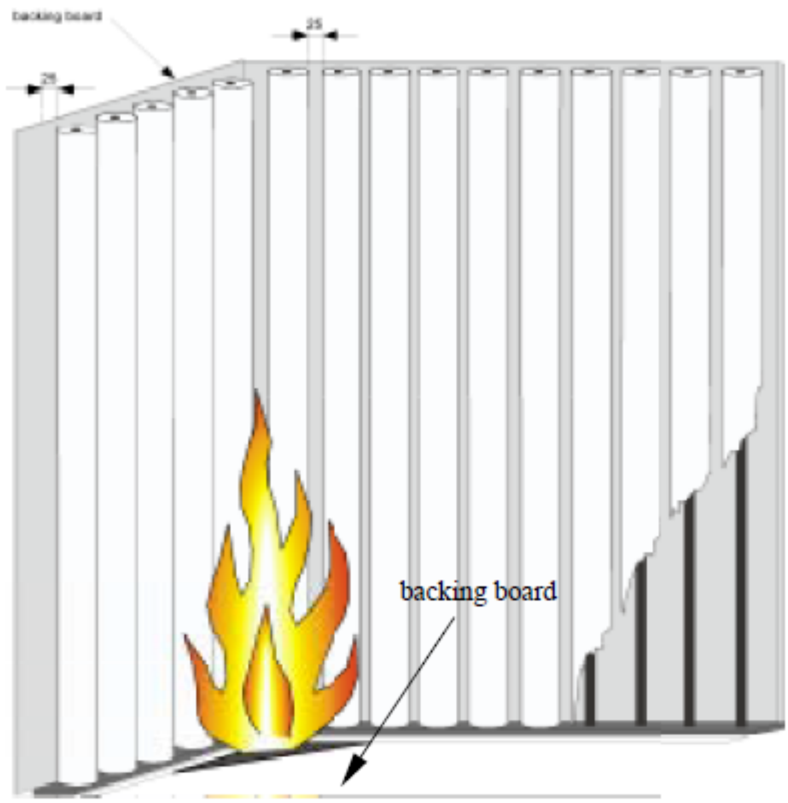


Figure 12 Schematic showing the mounting of the pipe insulation in the EN 13823 test (extracted from Sundström & Axelsson, 2002)

9. FIRE PERFORMANCE OF HVAC DUCTS

9.1 Introduction

9.1.1 Flexible ducts

Two components of flexible ducting products have an impact on the fire performance of the material – the insulation and the lining/sleeve.

Combustible insulation provides most of the fuel for the fire and the more insulation that is present, proportionally, the more fuel is available to burn and the more intense the resulting fire for a given material. More insulation (and potential energy content) can be either as a result of thicker and/or denser insulation being present.

Depending on its nature, the duct lining material can have a significant effect on the fire propagation mechanism. If the outer lining material can maintain its integrity, a greater proportion of the insulation will become involved in the fire as flame spreads along the length of the ductwork. This results in a more intense fire.

A thin flexible plastic outer sleeve material will rapidly melt in a fire and may not provide a sustained fire propagation pathway. In comparison, more rigid aluminium/foil sleeves may maintain their integrity long enough to support the insulation and involve the greater proportion of the available insulation fuel in the developing fire.

Although flexible ducting of the type commonly used in New Zealand performs poorly when exposed to a developing fire, the relatively limited number of duct runs and short lengths of flexible ductwork help mitigate the overall risk.

9.1.2 Rigid ducts

Ductwork constructed from more rigid materials is generally stronger, larger and has longer runs compared to flexible ductwork. Rigid ductwork materials will therefore generally remain in place for longer. Combustible materials may exhibit potential for flame spread along the length of the ductwork, both internally and externally depending on the construction and the materials.

9.2 Room-scale fire experiments – Flexible duct external fire exposure

9.2.1 Description

Six room/corner ad-hoc fire tests were conducted to investigate the effect of fuel load and support conditions. The tests used various linear runs of flexible ductwork mounted within the room using three variations of flexible duct design

All three types of flexible duct used nominal 10 kg/m^3 R0.6 lofted polyester as it represented the vast majority of the flexible duct insulation used in the marketplace.

Testing was carried out within a small concrete room (2.4 m wide x 3.6 m long x 2.4 m high) with a door opening of 0.8 m x 2.0 m high located in one of the short walls. This is the same room and apparatus used for ISO 9705 room fire testing on surface linings (ISO, 1993) and in ISO 20632 for pipe insulation (ISO, 2009).

The insulated flexible ductwork, purchased from New Zealand fabricators was subjected to a propane gas burner in the corner of the room. The burner had an output generally following that used for the classification of surface linings using the Group Number System (i.e. 100 kW for ten minutes and increased to 300 kW thereafter). The ISO 9705 fire test allows for the combustion gases, on discharge through the room opening, to be collected in a hood and exhausted to the outside via an extractor duct. The oxygen concentration in the combustion products and the smoke optical density is measured throughout the test duration. This allows the rate of heat release and smoke production rate to be calculated.

The three duct types were:

- **Duct A** – 300 mm inside diameter flexible ducting, comprising a spiral-wound wire-reinforced plastic film inner liner, nominal 25 mm thick polyester insulation (nominal 250 g/m^2) with an unreinforced plastic film outer sleeve.
- **Duct B** – 300 mm inside diameter flexible ducting, comprising a spiral-wound wire-reinforced aluminium foil laminate inner liner, nominal 25 mm thick polyester insulation (nominal 250 g/m2) with an aluminium foil laminate outer sleeve.
- **Duct X** – 150 mm inside diameter flexible ducting, comprising a semi-rigid aluminium inner liner, nominal 50 mm thick polyester insulation (nominal 500 g/m^2) with an unreinforced plastic film outer sleeve.

The only difference between Ducts A and B appeared to be in the construction of the inner and outer sleeves with Duct B sleeves being a heavier-weight foil laminate construction with a smaller pitch spiral winding. Figure 13 illustrates Ducts A and B. The 300 mm inside diameter ducting matched the diameter used in the AS 4254 testing regime. Figure 14 illustrates Duct X.

The products purchased were examples of flexible ducting in common use in New Zealand. They did not necessarily represent a worst case in terms of the duct size, or thickness or density of the insulation.

Figure 13 Photographs of flexible round ductwork, Duct A (left) and Duct B (right)

Figure 14 Photograph of flexible round ductwork, Duct X

Tests 1-4 were conducted using Duct A, Test 5 using Duct B and Test 6 using Duct X.

For Tests 1-3, the ducts were installed within the room by draping them over steel supports located approximately 400 mm below the ceiling and spanning across the shorter room dimension as shown in Figure 15. This arrangement provided intermittent support to the ducts and for Tests 1, 2 and 3, one, two and three runs of ductwork were respectively installed within the room. Each run of ducting comprised two 3 m lengths, with one length pushed inside the other at the join. The vertical section of duct was hung over the ceiling support and terminated above the gas burner.

In Tests 4 and 5, additional support was provided by placing a steel mesh between the ducts and the support channels as shown in Figure 16 to prevent sections of burning duct collapsing between the support channels. The steel mesh covered only part of the length of the room. The remaining length was spanned using a short length of steel channel inserted inside the duct and resting over the horizontal support channels. This alternative method of supporting the ducts better simulated ducts resting upon the top surface of a suspended ceiling and prevented large pieces of ducts dropping to the floor during the test.

In Test 6, a different continuous support arrangement was used where round steel pipe was run internally through the ductwork. Three runs of ductwork were installed vertically in the corner where the burner was placed and along the wall/ceiling intersections along both long walls and the rear wall in the room as shown in Figure 17. The vertical runs of duct in this test were held up with insulation pins to prevent the insulation slumping in the open-ended ductwork. The additional support provided to the ducts in Tests 4-6 was expected to lead to more intense burning. This was because the combustible material would present for longer in a position subjected to higher temperatures with flame impingement.

The bottom ends of the ducts above the gas burner were open, exposing the inner and outer sleeves and insulation to direct flame. For Test 1 and 2, the gas burner was located in the corner of the room. The corner location provides a more severe exposure condition because entrainment or surrounding air into the burner plume is reduced, leading to a taller flame. The taller flame exposes a greater surface area of duct.

For Tests 3-5, the burner was moved approximately 500 mm sideways along the wall to be positioned beneath the middle of the three hanging ducts. The general arrangement is shown in Figure 15 and Figure 16. This position for the burner was selected to minimise the time for all three ducts to ignite and contribute to the burning.

A summary of the key test parameters is given in Table 7.

Table 7 Summary of test parameters

	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
Duct	A	A	A	A	B	X
Number of linear duct runs	1	2	3	3	3	3
Continuous support	No	No	No	Yes	Yes	Yes
Total internal surface area of duct[1] (m^2)	5.7	11.3	17.0	17.0	17.0	16.3
Mass of polyester insulation[2] (kg)	1.4	2.8	4.2	4.2	4.2	8.2

1 Estimated based on the inside diameter and length of the ductwork

2 Estimated based on the nominal density of insulation and inside surface area of ductwork

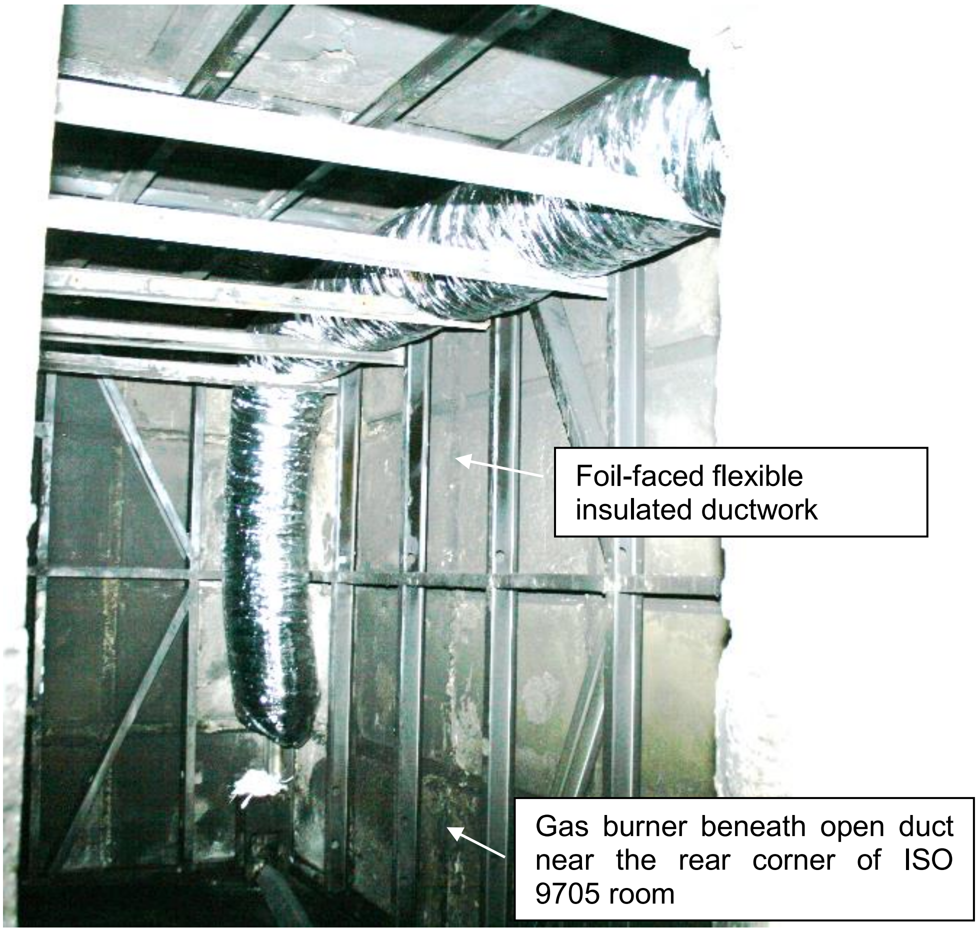


Figure 15 Duct installation method used in Test 1. Tests 2 and 3 similar with two and three duct lengths installed respectively

Figure 16 Duct installation method used in Tests 4 and 5 (three runs of duct shown)

Figure 17 Duct installation method used in Test 6 (three runs of duct shown)

9.2.2 Results

Table 8 summarises the rate of heat release (RHR) and smoke production rate (SPR) measured during each test.

Figure 18 shows the measured RHR based on oxygen consumption calorimetry using ISO 9705 procedures for Tests 2 to 5. Figure 19 shows the measured SPR in the collection duct for Tests 2 to 5.

Comparing Tests 3 and 4 shows the effect of providing continuous support to three runs of ductwork with the peak RHR almost doubling. The peak SPR also doubled.

Comparing Tests 4 and 5 shows the effect of using the heavier aluminium foil sleeves compared to the lighter-weight silver foil sleeves, both provided with continuous support. Test 5 with the heavier foil sleeves reached a higher peak RHR, slightly lower peak SPR and a more sustained period of burning.

Comparing Tests 2 and 3, surprisingly the two runs of ducts performed worse than when three ducts were present with a higher average and peak RHR measured. This may have been due to the changed location of the gas burner away from the corner. This placement is usually associated with a slightly less severe exposure due to increased entrainment into the fire plume.

Duct B used in Test 5 was observed to result in the most severe outcome of the five tests with a peak rate of heat release of 752 kW measured after only 57 seconds. Taking into account the heat release contributed by the gas burner, approximately 650 kW was contributed by the burning duct materials. Flashover may have been reached if a greater mass of combustible material had been present in the room.

Duct X in Test 6 was a smaller diameter ductwork (150 mm inside diameter) compared with Tests 1-5 and with longer run lengths along the wall ceiling junctions. The initial fire growth rate was also the slowest of the five tests, with less ductwork initially exposed to the burner flame. However, the heat release rate after 600 seconds was higher. In this configuration, more of the fuel load was positioned away from the burner compared to the first five tests. When the burner output was increased the flame length in the corner also increased contributing to further flame spread and an increased rate of burning.

See Appendix A to Appendix F14.Appendix F for photographs taken during each of the tests.

Table 8 Summary of results

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Avg SPR 0-10 min (m^2/s)	Not available	1.1	0.9	2.5	4.1	1.5
Peak SPR (m^2/s)	Not available	9.5	9.7	19.9	18.2	3.7
Avg RHR 0-10 min (kW)	Not available	144.7	134.8	182.4	244.4	174
Peak RHR (kW)	Not available	432	363	622	752	429
Flaming droplets/particles	Yes	Yes	Yes	Yes	Yes	Yes

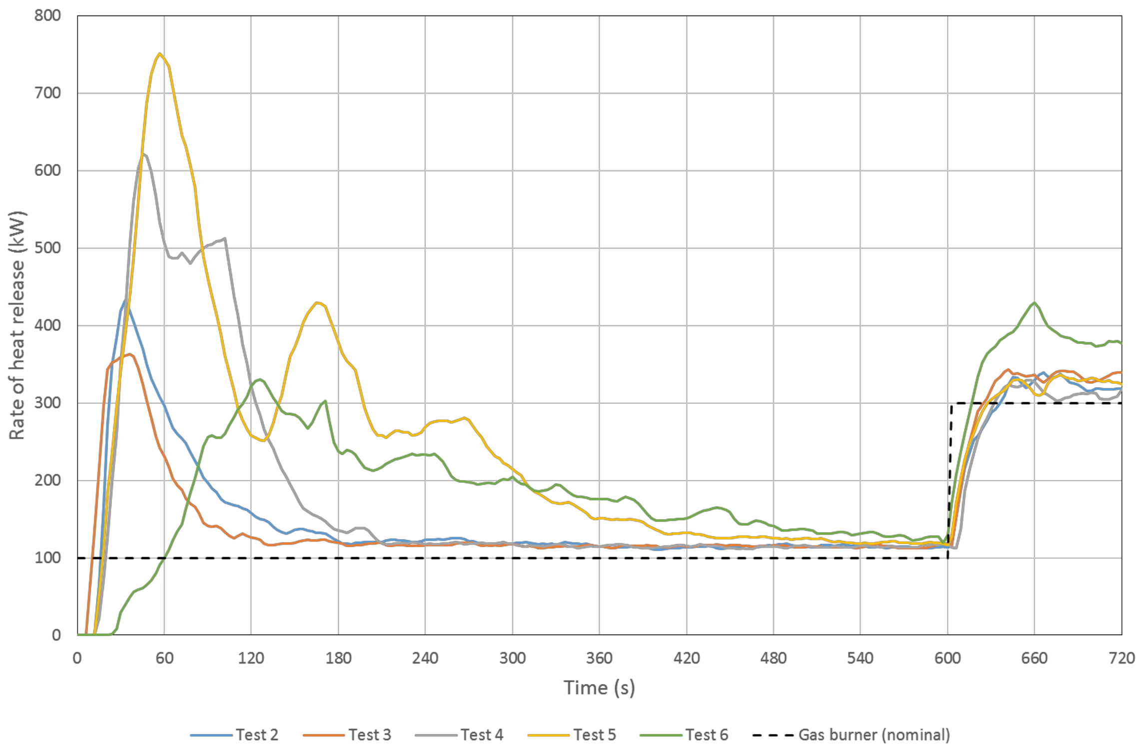


Figure 18 Measured rate of heat release versus time

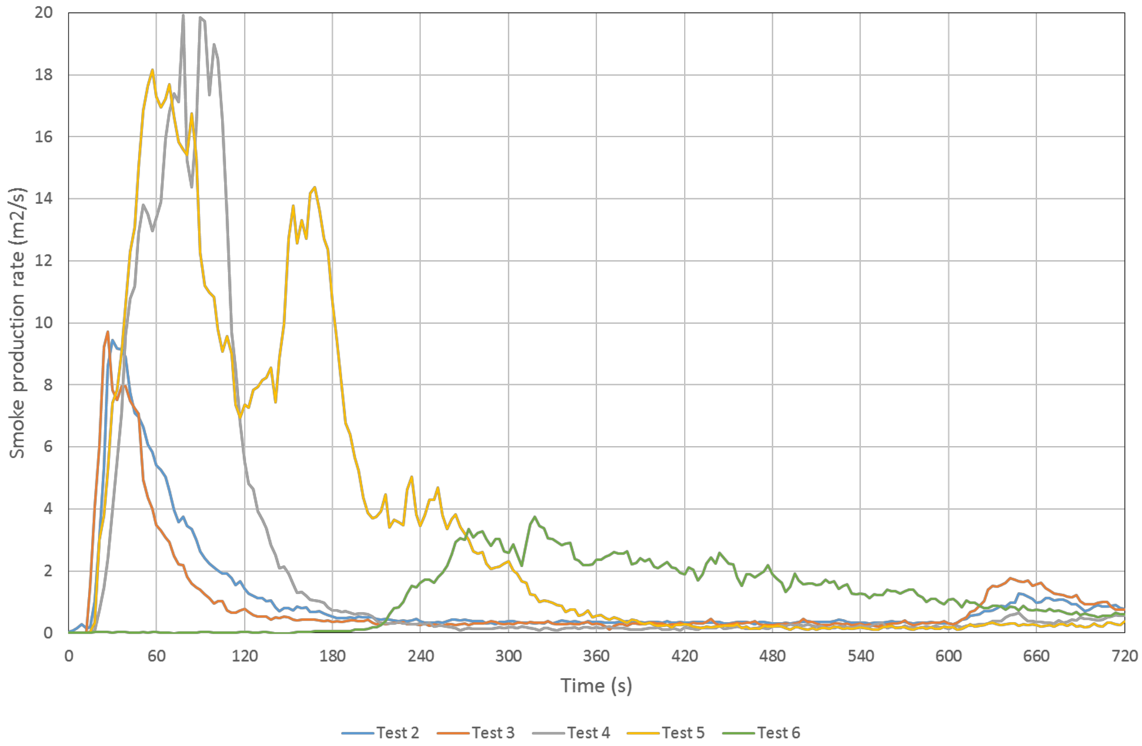


Figure 19 Measured smoke production rate versus time

9.2.3 Discussion

None of the product configurations tested reached the flashover criteria used as part of the Group Number System for surface linings. However, care is required in drawing the conclusion that the performance is therefore satisfactory since ducts are typically installed in addition to the surface lining materials. The Group Number System criteria is closely related to the specific requirements of the ISO 9705 room test requiring the walls and ceiling surfaces to be lined with the test product. Therefore the testing carried out here could not be used to assign a Group Number.

In this series of tests on flexible ductwork we investigated the effect of installing ducts in a more representative three-dimensional linear configuration. We also included different quantities of combustible material within the room as given in Table 7.

The total mass of insulation present in the room in these tests was relatively low considering the low density of the insulation material. Had other types and density of insulation been used as might be typical for insulating rigid ducts, a more severe fire and greater heat release could have been expected.

Figure 20 Flaming droplets from the polyester insulation, ceiling-supported ducts

Flaming droplets or particles persisting longer than ten seconds were observed in all six tests on externally-insulated ducts carried out for this investigation. This was mainly the result of the polyester insulation melting and dripping. Figure 20 and Figure 21 illustrate examples of this. Flaming droplets provide a mechanism for the fire to spread by igniting other combustible furnishings that may be present below the ductwork. In addition, because fire spread to the ductwork was very rapid, flaming droplets could also represent a potential hazard to occupants as they attempt to escape. This is more likely in the case where the ductwork is exposed to view from the occupied space.

Ducts A, B and X are typical of commercially-available products and their construction. They meet the fire test criteria within AS 4254 Part 1 (i.e. AS 1530.3 and the UL 181 burning test).

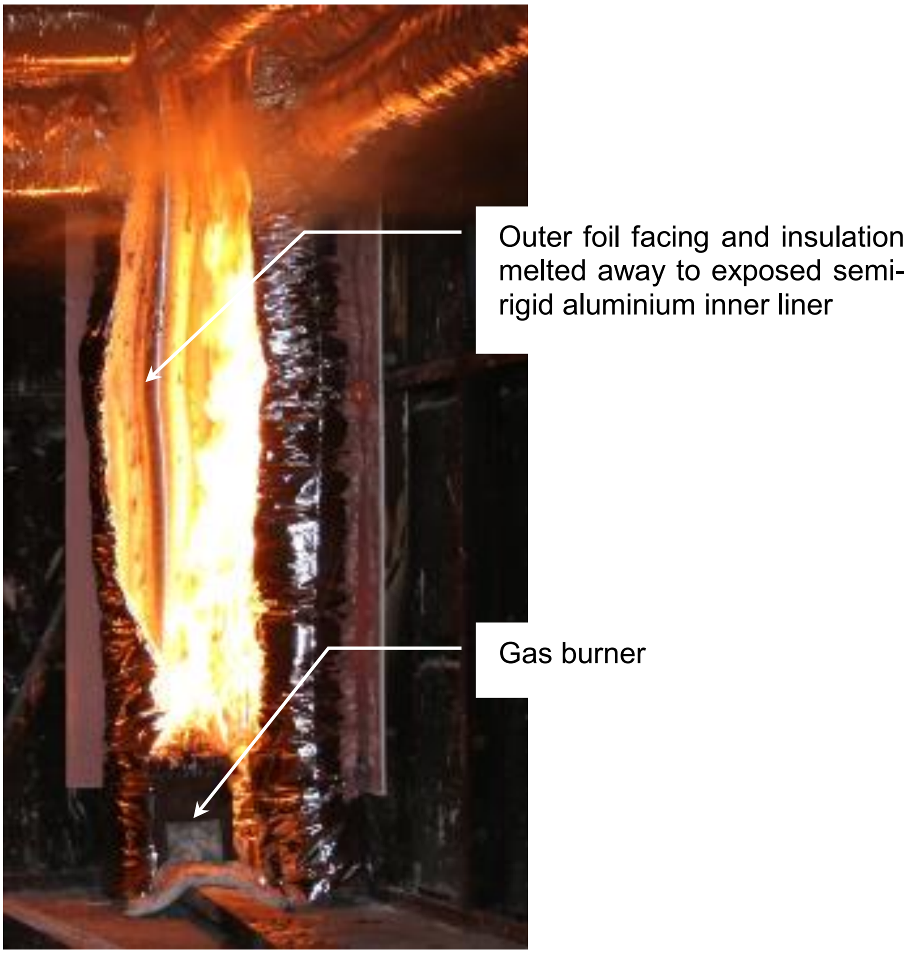


Figure 21 Flexible duct in Test 6 after 34 seconds

9.3 Room-scale fire experiments – Rigid duct internal fire exposure

9.3.1 Description

An experiment was conducted mounting two parallel runs of 300 mm inside diameter galvanised steel duct vertically and along the ceiling wall corners of the ISO 9705 room as shown in Figure 22. The duct was insulated with a commercially-available high-density polyester insulation, 50 mm thick and of nominal density 44.6 kg/m^3, and is shown in Figure 23. Technical literature for the product indicated the insulation achieved Group 1-S to ISO 9705 (i.e. tested as flat sheet on the walls and ceiling).

Single lengths of open-ended ducts were used, i.e. with no bends or connectors. The total ductwork length in the room was 9.2 m and the total mass of insulation present within the ducts was 19.5 kg.

The gas burner was located in the corner of the room directly beneath the open ends of two ducts. The burner output was 100 kW for the first ten minutes followed by 300 kW for a further ten minutes.

This test scenario was intended to maximise the potential for the internal duct insulation to ignite and contribute to the fire.

Figure 22 View of duct installation prior to test

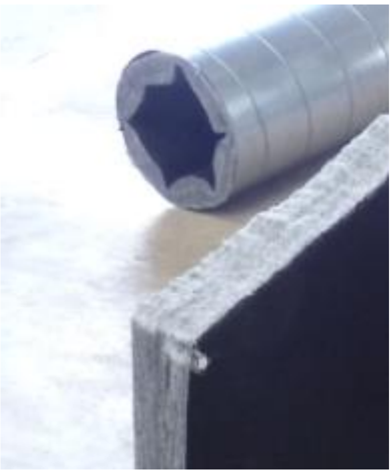


Figure 23 View of insulation sheet and as fitted inside steel duct

9.3.2 Results

The peak rate of heat release from the insulation material alone was 1500 kW (excluding the burner). The measured rate of heat release is shown in Figure 24. The measured smoke production rate is shown in Figure 25.

The insulation was observed to melt and drip onto the floor surface as shown in Figure 26. Figure 27 shows flames extending from the room opening soon after flashover. This was closely followed by some of the ductwork collapsing onto the floor just inside the wall opening as also seen in the figure. This fuelled the fire further by allowing air/oxygen access to fresh fuel through the end of the duct at low level.

The test was terminated at 1045 seconds following flashover and an open sprinkler head in the room was operated to apply water to extinguish the fire.

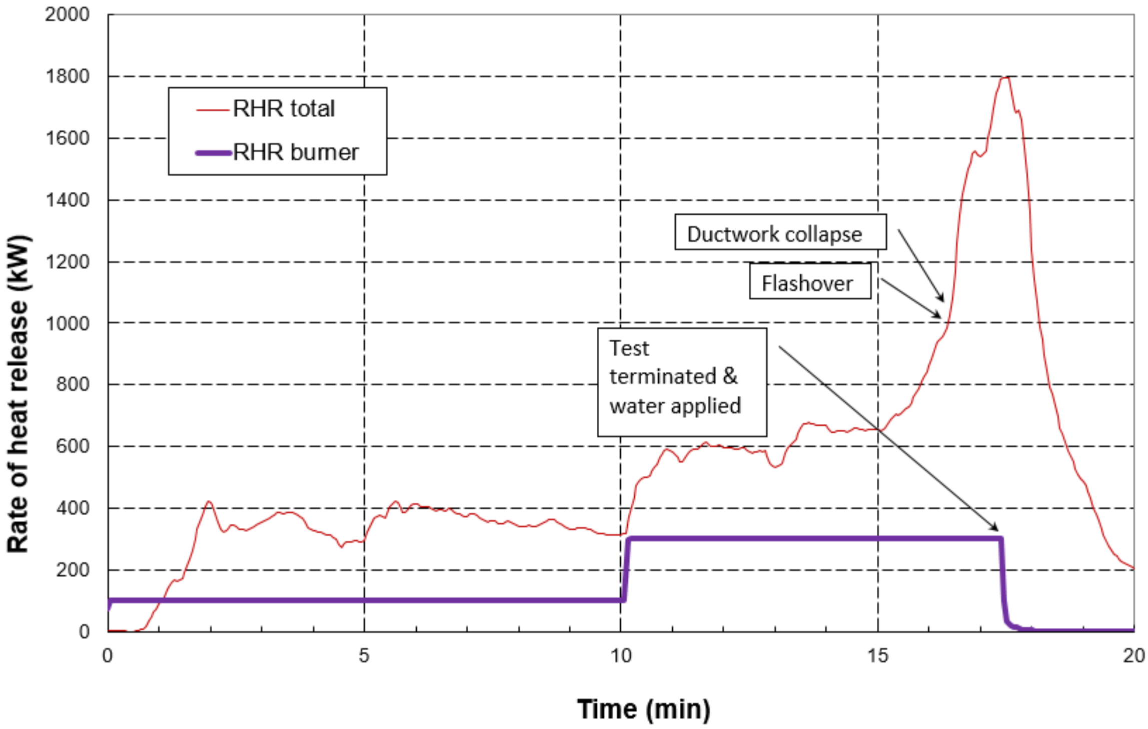


Figure 24 Rate of heat release for galvanised steel ductwork with 50 mm thick internal polyester insulation mounted within the ISO 9705 room

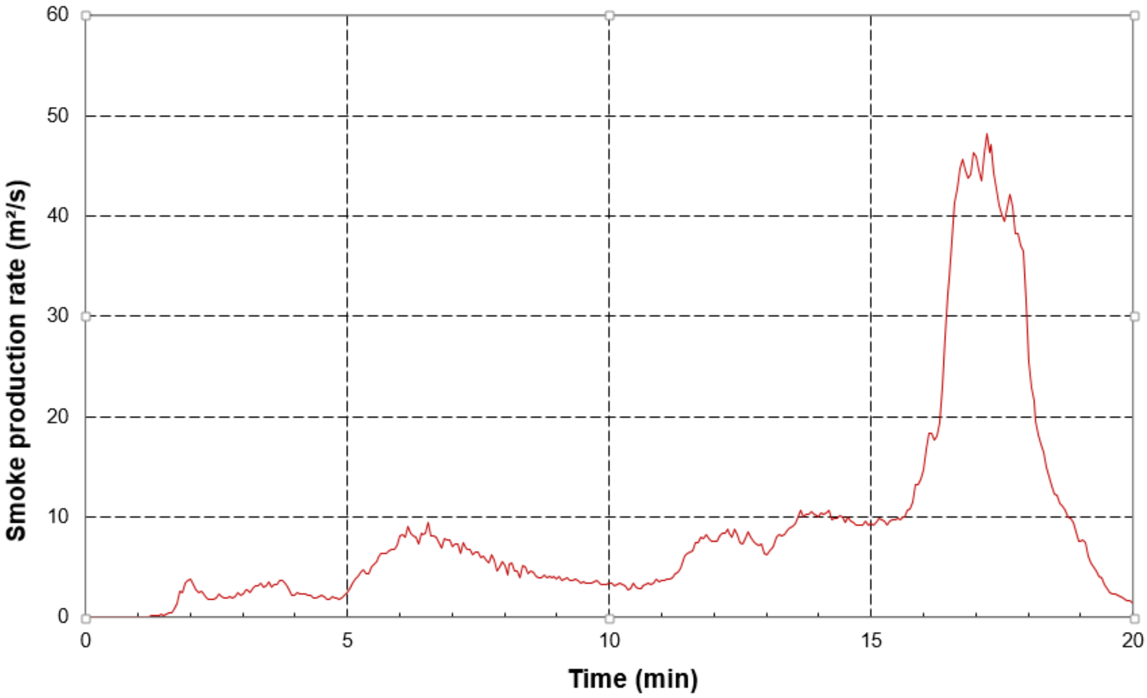


Figure 25 Smoke production rate for galvanised steel ductwork with 50 mm thick internal polyester insulation mounted within the ISO 9705 room

Figure 26 Molten polyester duct insulation burning on floor at 12:23 minutes

Figure 27 Flames emerging from opening, collapsed ductwork and burning insulation on floor at 17:47 minutes

9.3.3 Discussion

The confined (tubular) configuration of the insulation material within the steel ductwork led to greater intensity of burning compared to installation as a flat sheet on the walls/ceiling. The mounting of ductwork within the room differed from actual installation due to the separate pieces of duct lengths allowing access to air at each end. This was expected to be a worse case. The test configuration allowed molten polyester to flow from the metal ductwork and burn in a pool on the floor.

The higher density of insulation contributed to more intense burning (compared to the lower-density external insulation) due to the greater mass of fuel present.

See Appendix G for photographs taken during the test.

9.4 ISO 9705 Results for foil-faced polyester

Additional test data obtained from two different suppliers provides examples of an ISO 9705 test with different foil-faced duct insulation products installed flat on the walls and ceiling of the test enclosure. These materials are designated Products C and D here.

9.4.1 Product C

It is understood that insulation used in Product C was a denser material compared to that used in Products A, B and D, and it was installed on the ceiling and only part of the walls. Product C was a foil-faced insulation material intended in practice to be wrapped around a rigid duct liner.

In this test, flashover was reached with flames exiting the door opening in less than one minute. Figure 28 illustrates the measured rate of heat release during the test showing a peak value in excess of 2 MW. This is twice the level normally required to reach flashover in a room of this size. Following flashover, the smoke leaving the room was extremely black/dense with the smoke layer height close to floor level in the room. The fire was extinguished with water by operating an open sprinkler head in the room.

Under the Group Number System, Product C if installed as a wall lining, would be assigned a classification of Group 4. It would be considered a hazard with no applications under the New Zealand Building Code Clause C3.4.

The manufacturer advised that the product complied with AS 4254 and achieved AS 1530.3 SFI 0 and SDI not greater than 3.

See Appendix H for photographs taken during this test.

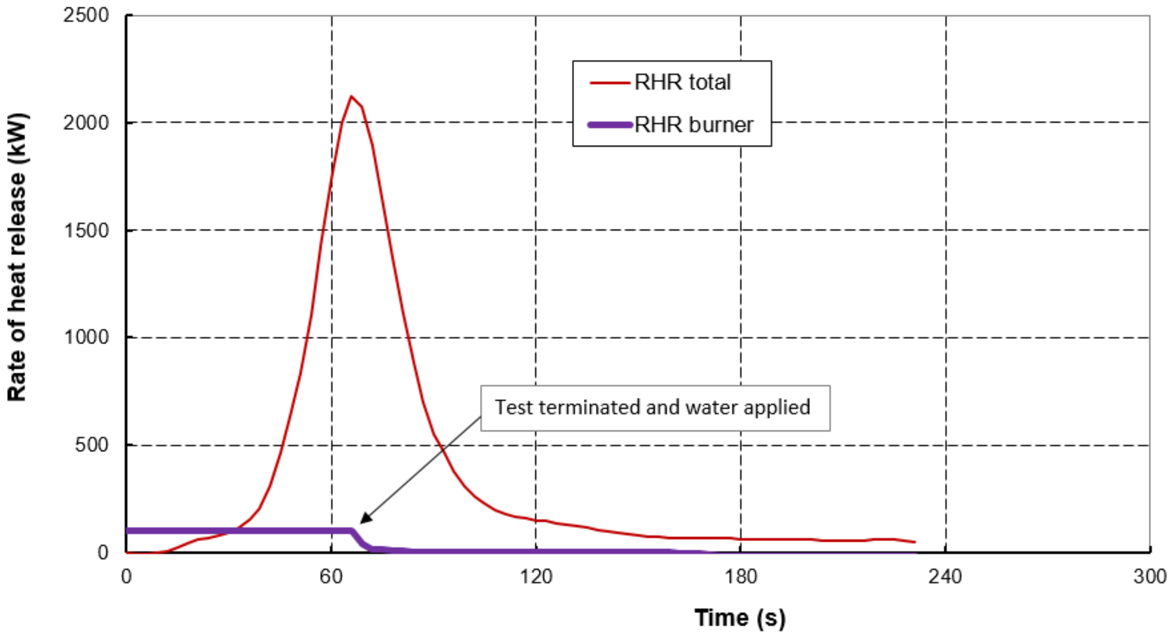


Figure 28 Rate of heat release during ISO 9705 test with Product C fixed to part of the walls and the ceiling of the room

9.4.2 Product D

It is understood that insulation used in Product D was a similar material and density compared to that used in Product A and B, and would pass the AS 4254 criteria.

In this test, the wire-reinforced metallised polyester tape facings melted back almost immediately on contact with the burner flame, with some droplets falling to the floor. By one minute, all material in the vicinity of the flame had melted away on the walls and ceiling. There was no significant change from this time until ten minutes when the burner output was increased to 300 kW. Flaming droplets of test material were then observed to rain from the ceiling and remained burning on the floor for a period. The room filled with thick black smoke. By 13 minutes the smoke density had reduced and the material lining the two long walls had melted in the upper part of the wall. Thereafter conditions did not change significantly until the end of the test at 20 minutes.

Figure 29 shows the measured rate of heat release during the test indicating only a small contribution by the test product over and above that contributed by the gas burner.

Under the Group Number System, Product D would be assigned a classification of Group 1-S and be considered suitable for any application under the New Zealand Building Code Clause C3.4.

See Appendix I for photographs taken during this test.

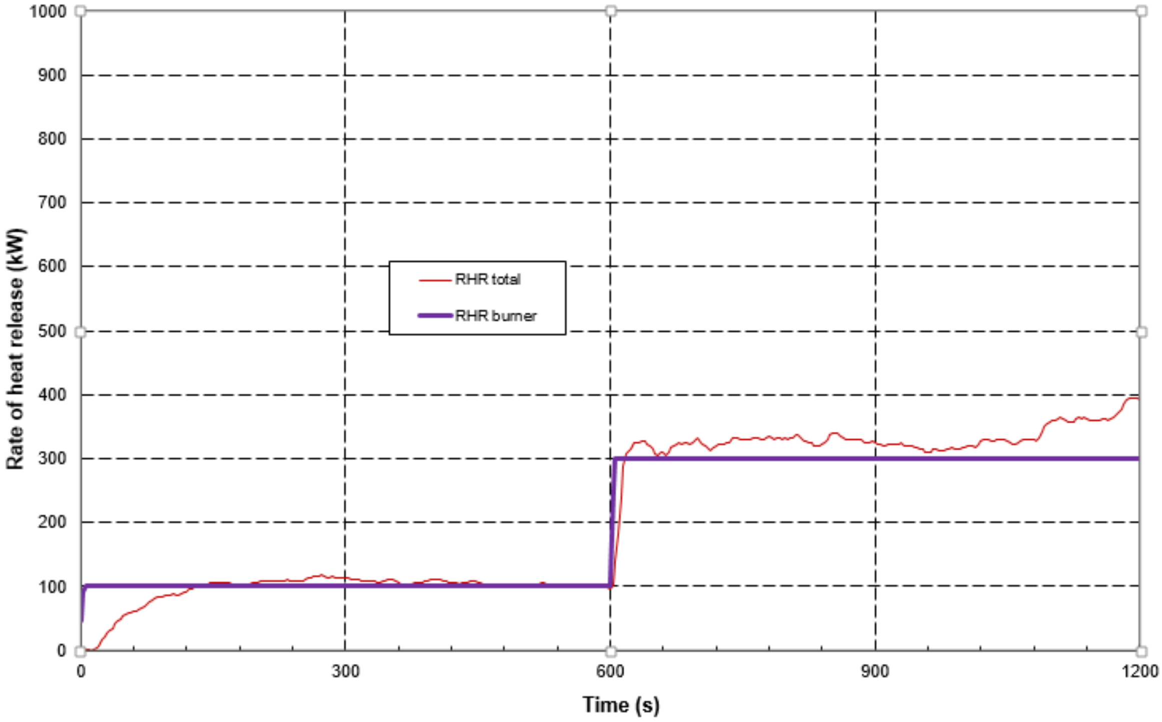


Figure 29 Rate of heat release during ISO 9705 test with Product D fixed to the walls and ceiling of the room

9.5 ISO 5660 Results for foil-faced polyester

9.5.1 Description

Indicative small-scale measurements of the rate of heat release of the polyester duct insulation previously used in the room corner tests were made using the ISO 5660 apparatus. The samples were exposed in a horizontal orientation to an irradiance of 50 kW/m^2 in the presence of the spark igniter.

The samples included:

- S1 – 25 mm thick foil-faced polyester (nominal 10 kg/m^3).
- S2 – two layers of 25 mm thick foil-faced polyester (nominal 10 kg/m^3).
- S3 – 50 mm thick high-density polyester (nominal 44.6 kg/m^3), black face unexposed.
- S4 – 50 mm thick high-density polyester (nominal 44.6 kg/m^3), black face exposed.

The measured rate of heat release is shown in Figure 30 and the average specific extinction area (in m^2/kg) is given in Table 9.

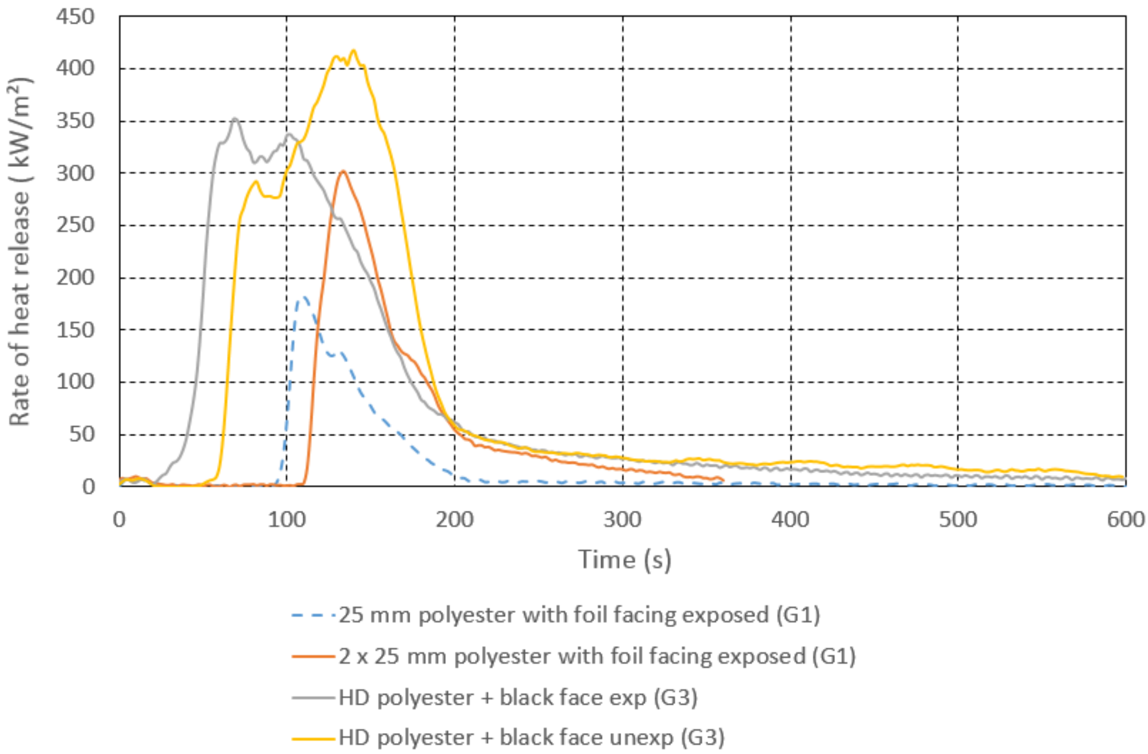


Figure 30 Polyester-based duct insulation rate of heat release per unit area versus time when exposed to an irradiance of 50 kW/m^2

Table 9 Smoke, average SEA for polyester-based duct insulation when exposed to an irradiance of 50 kW/m^2

Sample	SEA (m^2/kg)
S1	507
S2	446
S3	482
S4	420

9.5.2 Discussion

Testing polyester insulation using the ISO 5660 apparatus is not ideal since polyester shrinks and melts. Although burning still takes place, the distance between the conical heater and the liquid melt is greater (causing the received irradiance to be lower than intended). This effect will be influenced by the original thickness of insulation, with a thicker insulation leading to a greater distance between the melt and the heater and a correspondingly longer time to ignition. This can be seen in Figure 30 comparing the ignition time for the single layer of 25 mm polyester versus the double layer.

The procedure described in C/VM2 Appendix A for establishing a Group Number was applied using the results for each sample. The two thicknesses of foil-faced low-density polyester achieved a Group 1 classification and the two higher-density polyester samples achieved Group 3.

The Group Number result for the low-density foil-faced polyester sample was consistent with the ISO 9705 test result discussed in Section 9.4.2.

The specific extinction area (SEA) for all of the samples exceeded the 250 m^2/kg limit and therefore they did not meet the smoke criteria given in C/VM2 Appendix A based on the small-scale ISO 5660 test. Notwithstanding the above, C/VM2 Appendix A requires foil-faced combustible insulating materials to be tested to the full-scale ISO 9705 and not the ISO 5660 test.

10. FIRE PERFORMANCE OF PIPE INSULATION

10.1 ISO 20632 – Test of elastomeric foam pipe insulation

10.1.1 Product description

The product tested was a proprietary foamed nitrile rubber (elastomeric) pipe insulation with a nominal internal diameter of 22 mm and a nominal insulation thickness of 25 mm. The insulation had an apparent measured density of 72 kg/m^3 with an estimated total weight of approximately 23.4 kg.

Product literature stated that the product had been tested to AS 1530.3 and achieved spread of flame index 0 and smoke developed index 3. It was described as being non-dripping and non-contributing to fire.

10.1.2 Procedure

The test was conducted in accordance with ISO 20632 (ISO, 2009) except that the smoke measurement was carried out using a helium-neon laser instead of a white light system. This was not expected to adversely affect the results. Heat flux at the floor was also not measured.

An assembly of pipes with insulation fitted was mounted as specified by ISO 20632 (ISO, 2009).

The fire test room consisted of four walls at right angles, with the floor and ceiling at the following nominal dimensions – 3.6 m long x 2.4 m wide x 2.4 m high. A doorway was located in the centre of one of the 2.4 m x 2.4 m walls and this had nominal dimensions of 2.0 m high x 0.8 m wide. The opening discharged into a steel hood connected to an exhaust system that allowed for the collection of all combustion products and the completion of gas sampling and light obscuration measurements.

The test room was constructed of nominally 150 mm thick, lightweight concrete panels with a density of 560 kg/m^3.

The ignition source was a propane gas sand diffusion burner with a square (0.17 x 0.17 m) top surface at a height of 0.35 m above floor level. The burner was placed on the floor in a corner opposite to the doorway opening and positioned as close as possible to the specimen in the corner wall. The gas flow to the burner was set to generate a heat output of 100 kW for ten minutes followed by 300 kW for a further ten minutes.

Figure 31 shows the finished installation of insulated pipes in the room.

Figure 32 shows the elastomeric pipe insulation.

Figure 31 View of product installation prior to testing

Figure 32 Typical product image as shown in technical literature

10.1.3 Results

Observations made during the test are listed in Table 10. There were no flaming droplet or particles observed. The measured rate of heat release versus time is shown in Figure 33 and the measured smoke production is shown in Figure 34.

The peak rate of heat release was 528 kW at 714 seconds. There was no flashover reached during the 20 minutes' duration of the test.

Table 10 Test observations

Time min:sec	Description
0:50	A dense layer of smoke has developed, obscuring the view of the ceiling. The boundary of the smoke layer is approximately 1400 mm above the ISO room floor and is very well defined.
1:55	At this time there have been no flaming droplets and only a small amount of flaming that is localised to where the burner flame is in contact with the pipe insulation. There are ash-like flakes falling from the insulation onto the floor.
7:00	The smoke layer is now noticeably less dense. The smoke layer is approximately 1700 mm above the floor level.
8:30	The ceiling is now visible through the smoke layer.
10:00	Increase in burner heat output from 100 kW to 300 kW.
10:30	The smoke layer has become very dense again obscuring the view of the ceiling.
11:40	There is an increase in the amount ash-like flakes falling from the insulation.
13:50	The majority of the insulation is now gone from the vertical pipes next to the burner.
14:40	The layer of smoke has again become less dense and the ceiling is visible again.
20:00	The burner is switched off. No sustained flaming occurs.

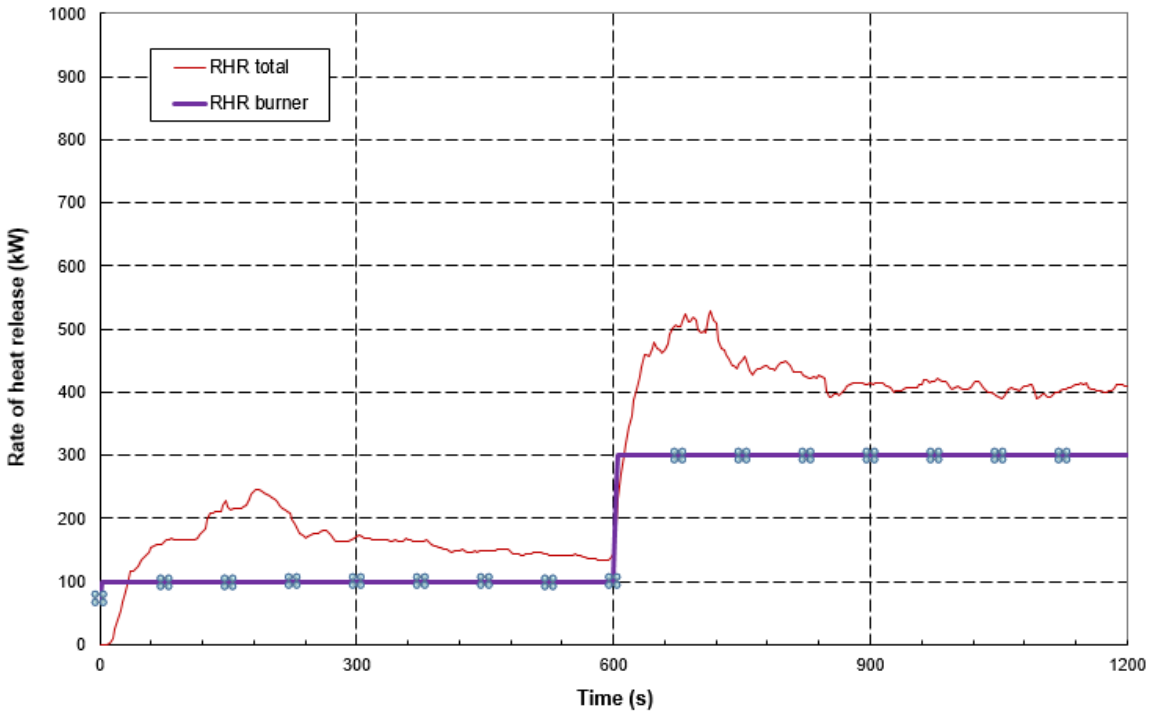


Figure 33 Rate of heat release for pipe insulation following ISO 20632

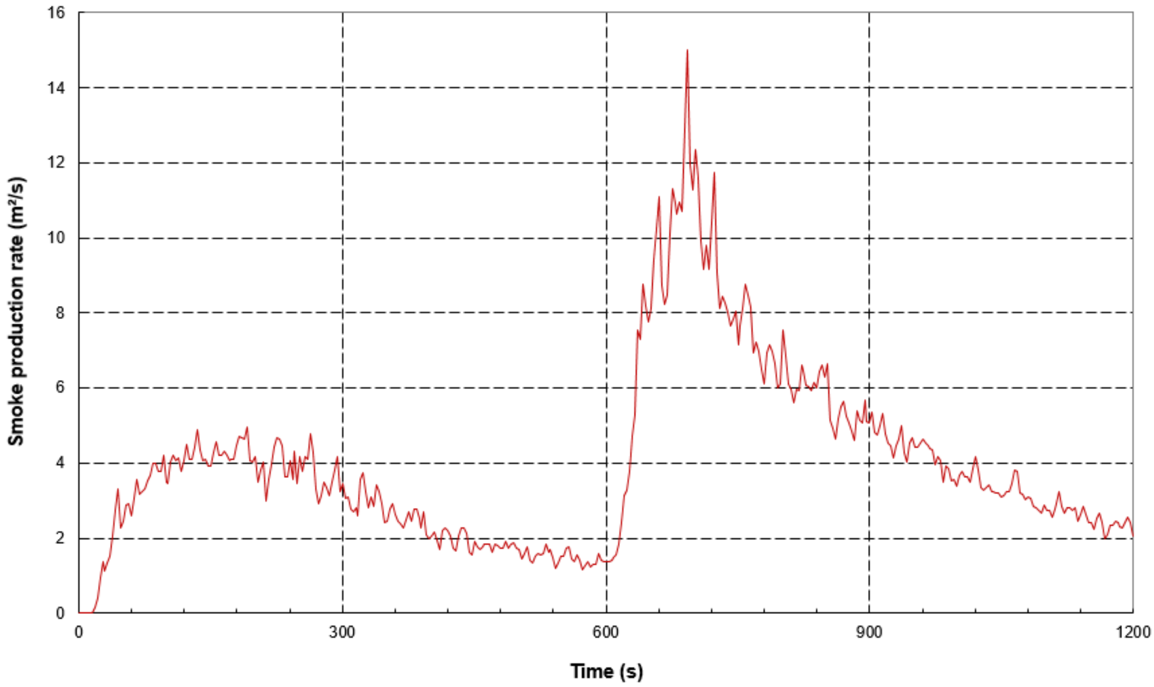


Figure 34 Smoke production rate for elastomeric foam pipe insulation following ISO 20632

10.2 ISO 5660 – Results for elastomeric foam pipe insulation

The same pipe insulation material (25 mm thick) used in the ISO 20632 test was also subjected to the small-scale ISO 5660 test and exposed to an irradiance of 50 kW/m^2. Three replicate samples of nominal 25 mm thickness were tested. The measured rate of heat release versus time is shown in Figure 35. A detailed summary of results is given in Table 11.

The mean for the three samples of the average specific extinction area over the duration of the test was 405 m^2/kg.

The procedure described in C/VM2 Appendix A for establishing a Group Number was applied using the results for each sample. Two of the samples achieved a Group 2 classification and the other (Sample 2) achieved Group 3. The product therefore would be classified Group 3 based on the highest Group Number of all three samples.

Product literature for the pipe insulation stated a Group 2 was achieved for 13 mm thick insulation based on ISO 5660.

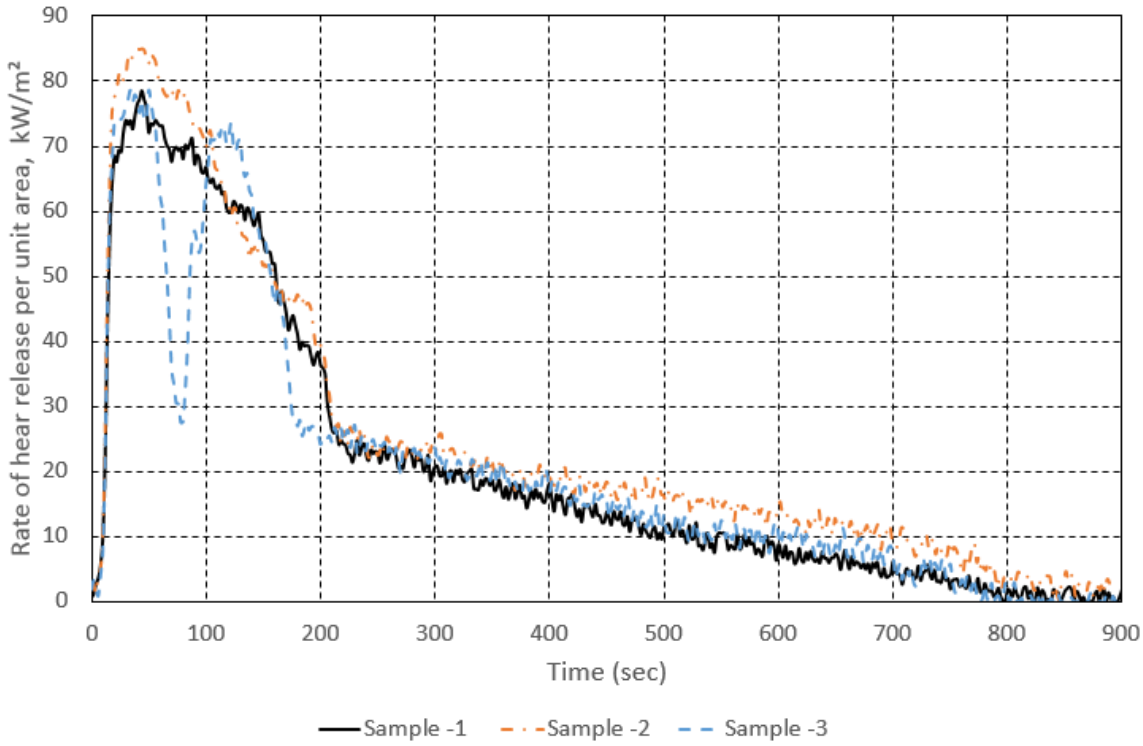


Figure 35 Elastomeric foam (25mm) pipe insulation rate of heat release per unit area versus time when exposed to an irradiance of 50 kW/m^2

Table 11 Elastomeric foam (25mm) summary of results when exposed to an irradiance of 50 kW/m²

Material		ISO5660 Data Files			Mean
Specimen test number		FQ0728-1-50-1	FQ0728-1-50-2	FQ0728-1-50-3	
Initial specimen mass	g	17.1	17.3	17.3	17.2
Mean specimen thickness	mm	24	24	24	24.0
Apparent overall specimen density	kg/m^3	71.3	72.1	72.1	71.8

Material		ISO5660 Data Files			**Mean**
Specimen test number		FQ0728-1-50-1	FQ0728-1-50-2	FQ0728-1-50-3	
Time to ignition	s	5	5	5	5.0
Observations		i	i	i	
Test duration	s	1266	1374	1300	1313
Mass remaining, m_f	g	3.8	2.4	2.7	2.9
Mass pyrolyzed	%	78.0%	86.0%	84.6%	82.9%
Specimen mass loss	kg/m^2	1.47	1.64	1.60	1.57
Specimen mass loss rate	$g/m^2.s$	1.2	1.2	1.2	1.2
Heat release rate					
$\dot{q}''_{max}$ peak	kW/m^2	78.6	85.1	78.7	80.8
$\dot{q}''_{avg}$ average					
Over 60 s from ignition	kW/m^2	61.8	69.6	62.1	64.5
Over 180 s from ignition	kW/m^2	60.2	64.2	55.9	60.1
variation from mean		0.2%	6.8%	-7.0%	OK
Over 300 s from ignition	kW/m^2	46.3	49.6	43.2	46.4
Total heat release	MJ/m^2	18.9	23.3	18.7	20.3
Average specific extinction area	m^2/kg	390.5	396.5	428.6	405.2
Effective heat of combustion	MJ/kg	12.6	13.9	11.3	12.6

10.3 Discussion

The correlation between the SBI test and the room test for pipe insulation was previously discussed in Section 8.1.2 with the FIGRA comparison shown in Figure 9. The development of the Euroclasses B to E for pipe insulation was based on the SBI FIGRA parameter as included in EN 13501-1 for the different classes. It is therefore possible to derive equivalent FIGRA for the room test corresponding to the SBI FIGRA which could be used as a guide to aid in the interpretation of the room tests on the linear products carried out in this study.

Figure 36 shows the correlation developed by Sundström and Axelsson (Sundström & Axelsson, 2002) for pipe insulation, along with the Euroclass limits based on $FIGRA_{SBI}$ for pipe insulation (CEN, 2007). The equation describing the correlation is also shown.

The $FIGRA_{RC}$ value for the elastomeric foam pipe insulation test described in Section 10.1 was 0.86 kW/s. Therefore it would be expected to fall within the Euroclass C_L or Group 2 (assuming a perfect correlation between $FIGRA_{SBI}$ and $FIGRA_{RC}$).

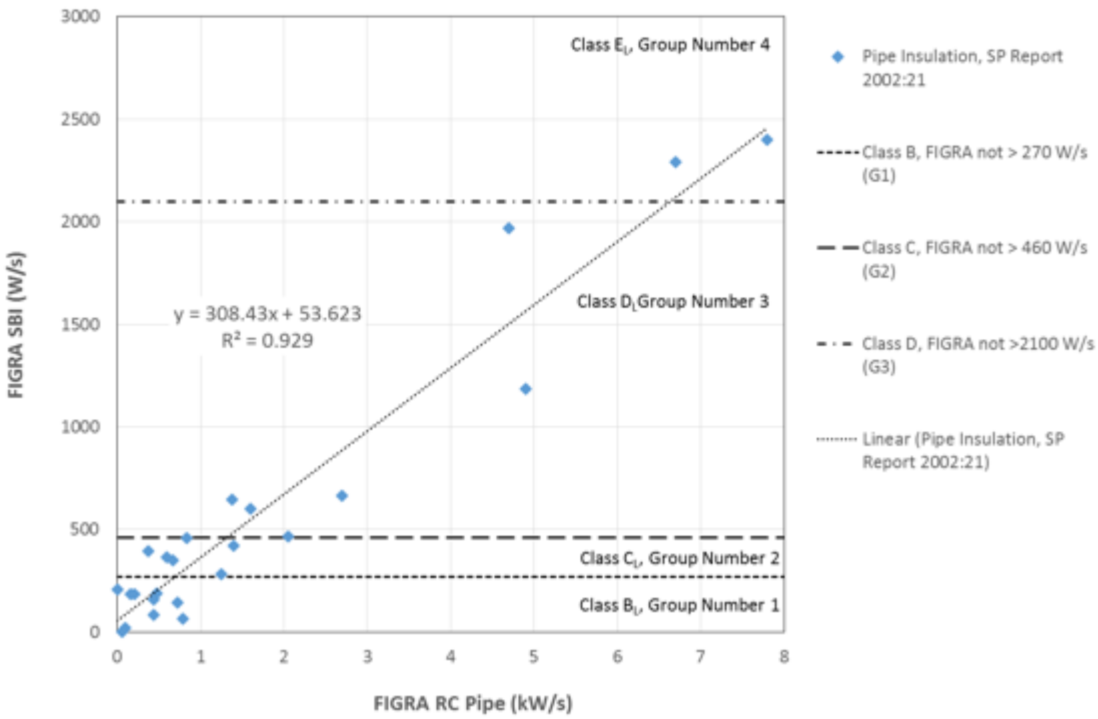


Figure 36 Correlation between the room/corner test and the SBI for FIGRA with Euroclass pipe insulation limits SBI shown (adapted from Sundström & Axelsson, 2002)

11. DISCUSSION

11.1 Exposed and unexposed ductwork

Ductwork may either be installed within ceiling spaces or within other plenums and shafts where it is separated from occupied spaces in the building. Alternatively it could be installed within an occupied space either as an architectural trend to visually express the ductwork, or within industrial or utility spaces where there is no functional need for a separate ceiling void.

The risk to occupants is generally considered greater where they are within the same space as the ductwork. For this scenario, the potential for flaming droplets from burning ductwork overhead is also a concern. Not only for the direct hazard caused to escaping occupants, but also the potential for falling droplets and debris to ignite other combustible furnishings and spread the fire.

Where the ductwork is separated from occupants, the immediate risk is lower. However there is still potential for the ductwork to provide a path for rapid smoke spread to other spaces served by the ductwork. A fire developing within a poorly-ventilated confined space such as a ceiling void is likely to become deficient in oxygen more quickly. This is accompanied by large increases in the production of smoke and carbon monoxide compared to a well-ventilated fire. In the case of flexible ducting supplying air diffusers to rooms, a means of transporting highly-concentrated and hazardous combustion products to nearby occupied spaces is available. This bypasses the protection afforded by the rest of the ceiling. This is of greater concern in sleeping occupancies and reinforces the need for automatic smoke detection and alarms in these buildings.

11.2 Ductwork in exitways

Prior to 2012 in New Zealand, all ductwork passing through exitways was required by the compliance documents of the time to be non-combustible. This ensured that ductwork material, if exposed to fire, would not contribute any significant heat or smoke to the developing fire. Exitways are those parts of the escape routes in buildings that are enclosed by fire-resistant construction and typically include protected stairs in multi-storey buildings.

Post 2012, the new Group Number requirements were introduced in NZBC Clause C3.4a for ductwork. This requires the internal surfaces of all ducts to meet not worse than Group 1 (unsprinklered) or Group 2 (sprinklered). The external surfaces require not worse than Group 3. This represents a substantial relaxation over the previous requirement for non-combustible duct materials in exitways. From the full-scale experiments described in this report it is clear that common flexible ductwork can produce significant amounts of heat and smoke. This occurs even when the requirements of Clause C3.4a are met. This relaxation is further exacerbated if the fire test methods used are unable to adequately discriminate fire performance of different duct materials.

It is noted that while NZBC Clause C3.4a and C/VM2 do not require non-combustible duct materials in exitways, the current Acceptable Solutions do have this requirement. It would be desirable to review the Code Clause relating to ductwork passing through exitways.

11.3 Fire test methods

As previously discussed in this report, the fire test methods cited by AS 4254 do not represent a sufficient challenge to ductwork materials.

In the case of the UL181 burning test, the Bunsen burner flame source is inadequately sized for other than a cigarette lighter ignition scenario. The purpose is to determine the response of the duct materials to fire at various inclinations including flaming droplet evaluation.

There have been international developments in fire hazard testing over the past decade for wall and ceiling surfaces (in New Zealand, Australia and throughout Europe). This also applies to pipe and duct insulation, facades and metal-faced composite panels (in New Zealand and throughout Europe). All these tests include exposure to moderate-sized flaming fire sources. This is done using the ISO 9705 scenario or the single burning item test (30-100 kW). These are far larger fire sources than a Bunsen burner flame. They are more representative of a waste paper basket-sized fire.

The other fire test method cited by AS 4254 is AS 1530 Part 3 and this does a poor job in assessing foil-faced insulation, as does ISO 5660 for the reasons discussed previously. However, ISO 5660 is suitable for rigid, non-thermoplastic duct materials and can be used with an empirical correlation to determine the Group Number for these materials.

Other materials require evaluation at a larger scale, e.g. using methods based on ISO 9705 and ISO 20632 in order to more accurately determine their expected behaviour in real buildings.

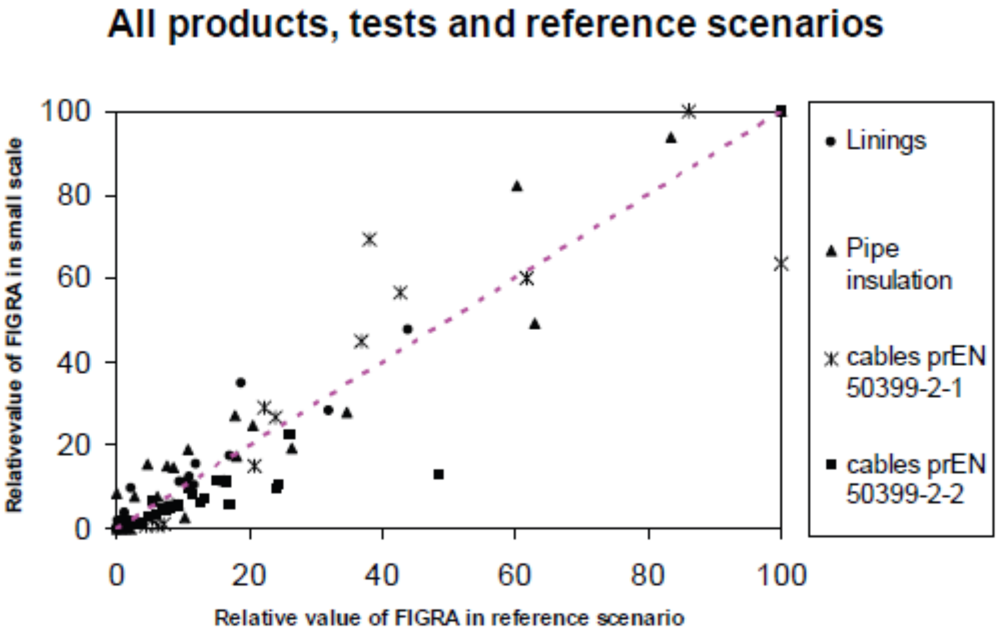


Figure 37 Correlation between small-scale and reference scenario for all data (normalised). Least squares correlation R^2 = 0.89 (extracted from Sundström, 2007)

12. CONCLUSIONS

This investigation did not uncover an extensive history of real fire incidents involving ductwork in New Zealand. There is no reason to believe that the vast majority of ductwork installed in New Zealand buildings presents any extreme risk, given the quantities of materials involved and their locations. However, the potential for ductwork to quickly distribute smoke via air diffusers to locations remote from the room of origin should be considered.

Flexible insulated (polyester) ductwork of the type most commonly used for air distribution in HVAC systems in New Zealand is readily ignited with a moderate flaming fire source and burns quickly and vigorously. Thin plastic flammable facings burn through quickly with the polyester insulation melting and dripping.

Continuous support of flexible combustible ductwork resulted in a worse fire performance by preventing early collapse of the ducting and allowing increased fire development to occur along the length of the ducting. Similar behaviour was observed for insulated rigid ductwork. In practice, this support could be provided by a suspended ceiling grid.

The extent of flaming droplets that were observed in the series of room tests conducted is of concern, especially where products are generally installed in exposed form overhead. Although undesirable, this behaviour can be expected from the use of the thermoplastic insulation materials. Flaming droplets pose a potential hazard to occupants and firefighters and provide a potential mechanism for secondary ignitions of building contents and structure.

The fire test methods (including AS 1530.3) used for assessing fire hazard properties of ductwork in AS 4254 do not adequately represent their full-scale performance. AS

1530.3 (and therefore AS 4254) does a poor job in discriminating fire performance and hazard of thermoplastic ductwork insulation. These same standards apply in Australia for the fire hazard properties of flexible and rigid ductwork.

Fire performance of insulated ductwork including thermoplastic insulation such as polyester is most appropriately assessed using a full-scale room fire test. Where ductwork is constructed from or insulated with rigid and thermoset materials, a small-scale test such as ISO 5660 may be applicable. However, ISO 5660 is not a valid test method for determining the Group Number for foil-faced thermoplastic (melting) insulation products.

The Group Number system for regulating reaction to fire properties of wall and ceiling linings introduced in April 2012 is a suitable basis for evaluating the fire hazard of rigid and flexible ductwork.

13. RECOMMENDATIONS

Due to the small size of the New Zealand market, it is not advisable to develop a new fire test method for duct or pipe insulation materials only for use in this market.

It is recommended that a dual compliance pathway be put in place allowing the use of EN-certified products. This should apply to both ductwork and pipe insulation.

A deemed to comply classification for polyester flexible duct is recommended. Group Number 1-S could be assigned to flexible duct constructed from foil-faced, lofted polyester blanket with a polyester thickness not greater than 50 mm and a nominal density no greater than 12 kg/m^3. As this specification of flexible ductwork is often assembled by small fabricators who order the materials required from other suppliers, this will remove the need for duplicate testing by different fabricators.

It is recommended that all other duct materials be evaluated using ISO 5660 or ISO 9705 assessed in a flat sheet configuration as for a wall or ceiling lining.

It is recommended that internal surface finishes of HVAC ducts be non-combustible or meet EN class A1 or A2. It is also recommended that the current NZBC performance requirement permitting combustible ductwork materials to pass through protected exitways be reviewed.

It is recommended that external surface finishes of HVAC ducts be restricted in similar situations as would be required for walls and ceilings. Then means when exposed to view from occupied spaces.

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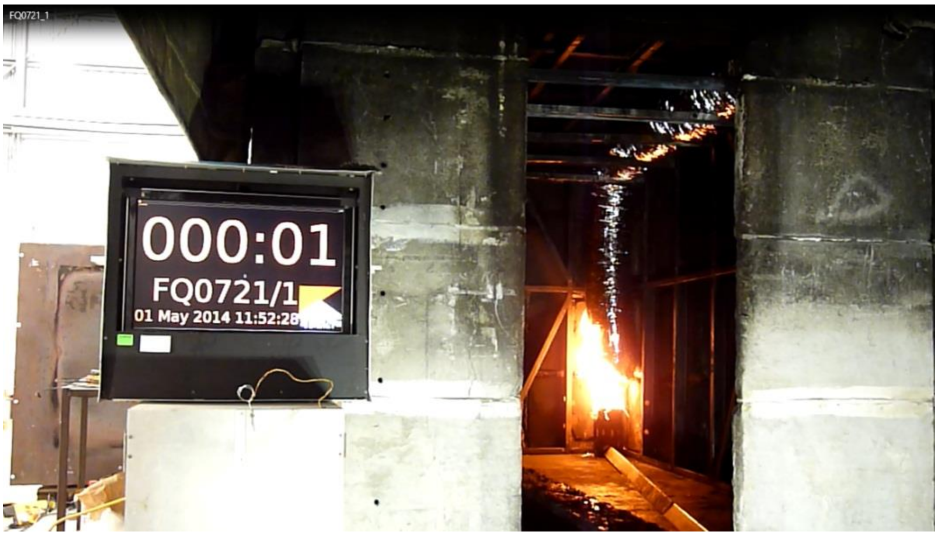
APPENDIX A TEST 1 – PRODUCT A (ONE RUN) INTERMITTENT SUPPORT

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000:20
FQ0721/1
01 May 2014 11:52:47


FQ0721_1
000:30
FQ0721/1
01 May 2014 11:52:57


FQ0721_1
000:45
FQ0721/1
01 May 2014 11:53:12


FQ0721_1
001:00
FQ0721/1
01 May 2014 11:53:27

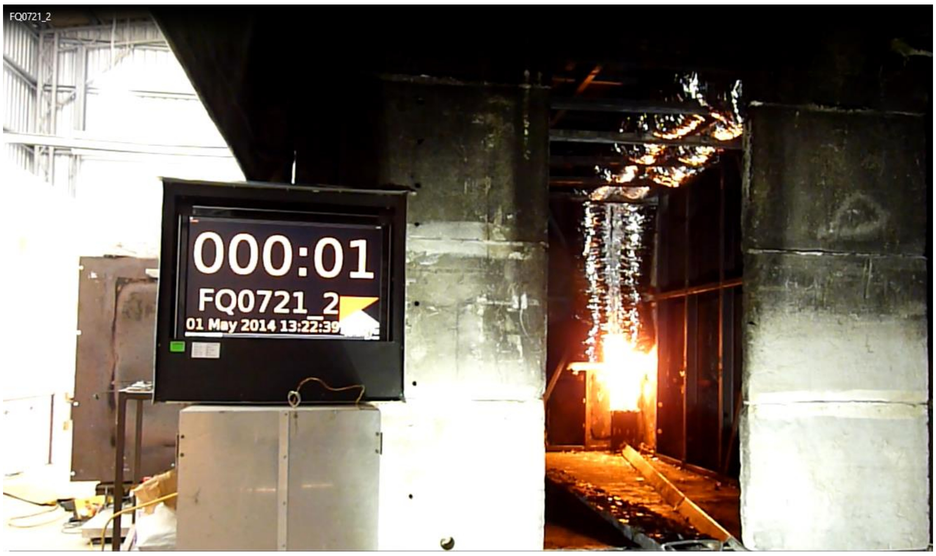

FQ0721_1
002:00
FQ0721/1
May 2014 11:54:27


FQ0721_1
010:00
FQ0721/1
01 May 2014 12:02:27


FQ0721_1
010:30
FQ0721/1
01 May 2014 12:02:57
BRANZ


FQ0721_1
012:00
FQ0721/1
01 May 2014 12:04:27
BRANZ

APPENDIX B TEST 2 – PRODUCT A (TWO RUNS) INTERMITTENT SUPPORT

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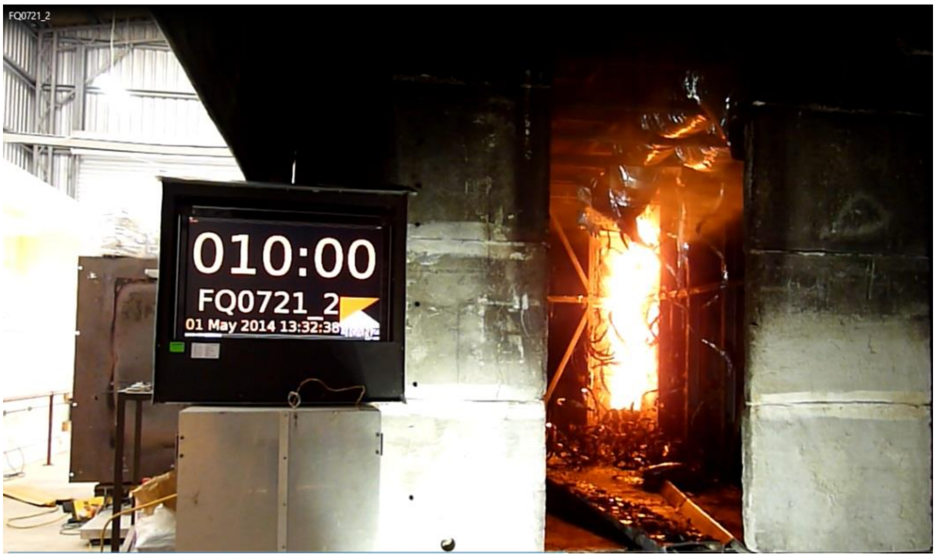
FQ0721_2
01 May 2014 13:23:08

FQ0721_2
000:45
FQ0721_2
01 May 2014 13:23:23

FQ0721_2
001:00
FQ0721_2
01 May 2014 13:23:38


FQ0721_2
002:00
FQ0721_2
01 May 2014 13:24:38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01 May 2014 13:32:38


FQ0721_2
010:30
FQ0721_2
01 May 2014 13:33:08


FQ0721_2
012:00
FQ0721_2
01 May 2014 13:34:38

APPENDIX C TEST 3 – PRODUCT A (THREE RUNS) INTERMITTENT SUPPORT


FQ0721_3
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FQ0721_3
01 May 2014 14:48:41


FQ0721_3
000:30
FQ0721_3
01 May 2014 14:48:51


FQ0721_3
000:45
FQ0721_3
01 May 2014 14:49:06


FQ0721_3
001:00
FQ0721_3
01 May 2014 14:49:21


FQ0721_3
002:00
FQ0721_3
01 May 2014 14:50:21


FQ0721_3
010:00
FQ0721_3
01 May 2014 14:58:21


FQ0721_3
010:30
FQ0721_3
01 May 2014 14:58:51

FQ0721_3
012:00
FQ0721_3
01 May 2014 15:00:21

APPENDIX D TEST 4 – PRODUCT A (THREE RUNS) CONTINUOUS SUPPORT


FQ0721_4
000:20
FQ0721_4
01 May 2014 16:10:11


FQ0721_4
000:30
FQ0721_4
01 May 2014 16:10:21


FQ0721_4
000:45
FQ0721_4
01 May 2014 16:10:36


FQ0721_4
001:00
FQ0721_4
01 May 2014 16:10:51


FQ0721_4
002:00
FQ0721_4
01 May 2014 16:11:51


FQ0721_4
010:00
FQ0721_4
01 May 2014 16:19:51


FQ0721_4
010:30
FQ0721_4
01 May 2014 16:20:21


FQ0721_4
012:00
FQ0721_4
01 May 2014 16:21:51

APPENDIX E TEST 5 – PRODUCT B (THREE RUNS) CONTINUOUS SUPPORT


FQ0721_5
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FQ0721_5
02 May 2014 14:55:30


FQ0721_5
000:30
FQ0721_5
02 May 2014 14:55:40


FQ0721_5
000:45
FQ0721_5
02 May 2014 14:55:55


FQ0721_5
001:00
FQ0721_5
02 May 2014 14:56:10

FQ0721_5
002:00
FQ0721_5
02 May 2014 14:57:10

FQ0721_5
002:20
FQ0721_5
02 May 2014 14:57:30


FQ0721_5
002:30
FQ0721_5
02 May 2014 14:57:40


FQ0721_5
003:00
FQ0721_5
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FQ0721_5
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02 May 2014 15:05:10


FQ0721_5
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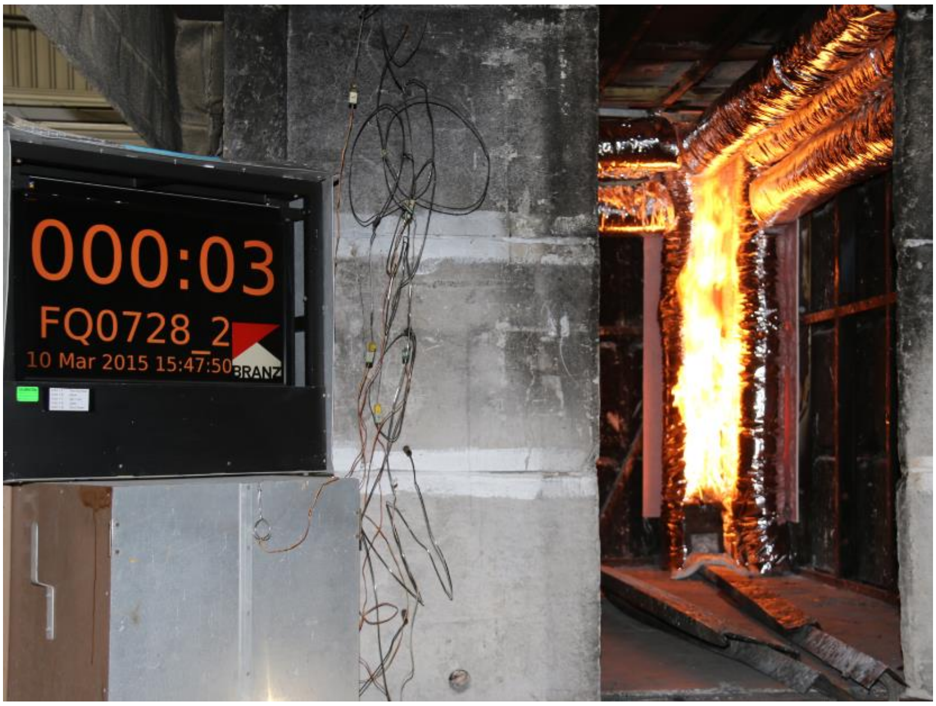
02 May 2014 15:07:10

APPENDIX F TEST 6 – PRODUCT X (THREE RUNS) CONTINUOUS SUPPORT

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10 Mar 2015 15:48:47
BRANZ


001:59
FQ0728_2
Mar 2015 15:49:46
BRANZ


002:31
FQ0728_2
10 Mar 2015 15:50:18
BRANZ


009:55
FQ0728_2
10 Mar 2015 15:57:42
BRANZ


010:23
FQ0728_2
10 Mar 2015 15:58:10
BRANZ

APPENDIX G TEST 7 – RIGID DUCT WITH INTERNAL INSULATION


001:50
FQ0728_3
26 Mar 2015 14:53:42


004:46
FQ0728_3

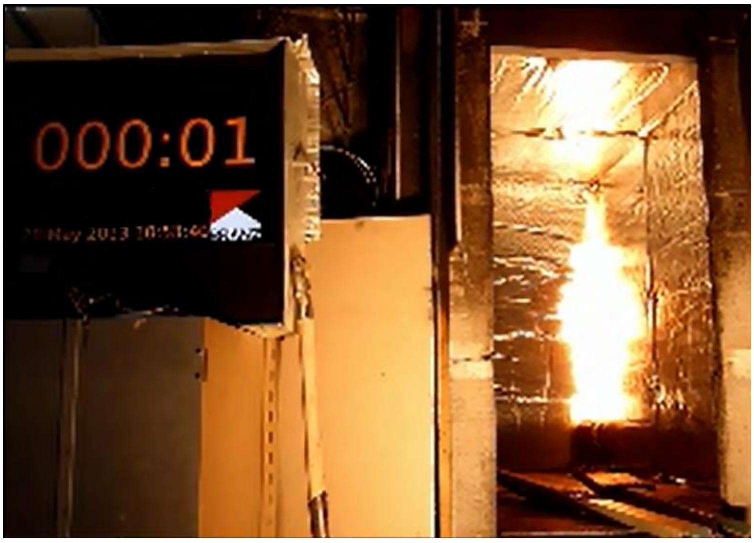

010:32
FQ0728_3
26 Mar 2015 15:02:24


012:23
FQ0728_3
26 Mar 2015 15:04:15


016:33
FQ0728_3


017:15
FQ0728_3
26 Mar 2015 15:09:07

APPENDIX H TEST 8 – ISO 9705 TEST – PRODUCT C




000:50


000:55


001:15

APPENDIX I TEST 9 – ISO 9705 TEST – PRODUCT D


008:18
BRANZ


009:59
BRANZ


015:02
BRANZ


019:59
BRANZ

APPENDIX J TEST 10 – ISO 20632 TEST – ELASTOMERIC PIPE INSULATION


00055
002:00
FQ0728 T1
10 Feb 2015 14:07:50


00055
004:00
FQ0728 T1
10 Feb 2015 14:09:50


00055
006:00
FQ0728 T1
10 Feb 2015 14:11:50


00055
010:05
FQ0728 T1
10 Feb 2015 14:15:55


00055
011:00
FQ0728 T1
10 Feb 2015 14:16:50


020:00
FQ0728 T1
10 Feb 2015 14:25:50

APPENDIX K EXTRACTS FROM C/VM2

IS design scenario

The smoke production rate criteria do not need to apply for sprinklered *buildings*.

Material *Group Numbers* apply to the exposed surface of the interior wall or ceiling lining. They are determined by the *fire* testing laboratory using the procedure described in Appendix A. This is either to:

a) ISO 9705, which is a full-scale room corner test, or

b) ISO 5660, which is a bench-scale fire test on a small sample of the material.

A correlation is used that allows the ISO 9705 result to be predicted using data obtained in the ISO 5660 test.

If an 'S' is appended to the material *Group Number*, the material also is required to meet smoke production criteria. The limit for maximum smoke production is:

a) 5.0 m^2/s if the ISO 9705 test is used, or

b) 250 m^2/kg if the ISO 5660 test is used.

Materials that are classified *non-combustible* when tested to AS 1530.1 or ISO 1182 can be assigned a material *Group Number* of 1 or 1–S without further evaluation using Appendix A.

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Rigid or flexible ductwork meeting the *fire* hazard properties set out in AS 4524 can be assigned a material *Group Number* of 1 or 1-s without further evaluation using Appendix A.

The minimum critical flux for a floor surface material or covering is determined by *fire* testing to ISO 9239 Part 1 (radiant panel test).

Method

The following tests should be applied to lining materials to achieve compliance with NZBC C3.4.

For wall/ceiling lining materials, external surface of ducts and pipe insulation:

a) Small scale testing to ISO 5660 (cone calorimeter test) provided it is appropriate for the type of material, or

b) Full scale testing to ISO 9705 (room corner test), or

c) Small scale testing to meet *fire* hazard properties set out in AS 4254 for rigid and flexible ductwork. Amend 3 Dec 2013

For floor surface materials:

a) *Fire* testing to ISO 9239 Part 1 (radiant panel test).

For suspended flexible fabrics and membrane structures:

a) *Fire* testing to AS 1530 Part 2 (flammability test).

A1.1 Tests for material Group Numbers

Materials shall be assigned a material *Group Number* when tested to either:

a) ISO 9705 Fire tests – full scale room test for surface products, or

b) ISO 5660 Reaction to fire tests (Heat release, smoke production and mass loss rate) Part 1: Heat release rate (cone calorimeter method); and ISO 5660 Reaction to fire tests (Heat release, smoke production and mass loss rate) Part 2: Smoke production rate (dynamic measurement).

This is except in the following cases:

a) Metal-skin panel assemblies with *combustible* core materials, which shall only be assessed using either the ISO 9705 or ISO 13784 Part 1 test method, or

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b) Foil-faced *combustible* materials, which shall only be assessed using the ISO 9705 test method, but if forming part of rigid and flexible ductwork may instead satisfy the requirements of A1.4 a), or

c) Other products that an accredited test laboratory believes are not appropriate to be evaluated using the ISO 5660 test method due to the configuration or other characteristics of the product. Such products shall be assessed using either the ISO 9705 test or another large scale test if deemed to be appropriate.

Comment:
ISO 5660 is unsuitable in cases where the *fire* performance of the assembly is dominated by the *construction* details rather than the flammability characteristics of the surface material or in cases where, due to the configuration of the material in the test, significant mechanical damage occurs at full scale which does not occur with small, horizontal samples.

A1.4 Determining a Group Number for surfaces of ducts for HVAC systems

Surfaces of rigid and flexible ductwork for *HVAC* systems shall be assigned either:

a) A material *Group Number* of 1-s when the ductwork complies with the fire hazard properties set out in AS 4254, or

b) A material *Group Number* as determined by A1.2 or A1.3.

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APPENDIX L EUROPEAN CLASSIFICATION CRITERIA FOR CONSTRUCTION PRODUCTS EXCLUDING FLOORING AND LINEAR PRODUCTS

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182 (1); *And*	$T \leq 30°C$; *and* $m \leq 50\%$; *and* $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	$PCS \leq 2.0\ MJ.kg^{-1}$ (1); *and* $PCS \leq 2.0\ MJ.kg^{-1}$ (2) (2a); *and* $PCS \leq 1.4\ MJ.m^{-2}$ (3); *and* $PCS \leq 2.0\ MJ.kg^{-1}$ (4)	-
A2	EN ISO 1182 (1); *Or*	$T \leq 50°C$; *and* $m \leq 50\%$; *and* t_f 20s	-
	EN ISO 1716; *And*	$PCS \leq 3.0\ MJ.kg^{-1}$ (1); *and* $PCS \leq 4.0\ MJ.m^{-2}$ (2); *and* $PCS \leq 4.0\ MJ.m^{-2}$ (3); *and* $PCS \leq 3.0\ MJ.kg^{-1}$ (4)	-
	EN 13823 (SBI)	$FIGRA \leq 120\ W.s^{-1}$; *and* LFS < edge of specimen; *and* THR_{600s} 7.5 MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
B	EN 13823 (SBI); *And*	$FIGRA \leq 120\ W.s^{-1}$; *and* LFS < edge of specimen; *and* $THR_{600s} \leq 7.5$ MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	$Fs \leq 150$mm within 60s	
C	EN 13823 (SBI); *And*	$FIGRA \leq 250\ W.s^{-1}$; *and* LFS < edge of specimen; *and* $THR_{600s} \leq 15$ MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	$Fs \leq 150$mm within 60s	
D	EN 13823 (SBI); *And*	$FIGRA \leq 750\ W.s^{-1}$	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	$Fs \leq 150$mm within 60s	
E	EN ISO 11925-2(8): *Exposure = 15s*	$Fs \leq 150$mm within 20s	Flaming droplets/ particles (7)
F	No performance determined		

(*) The treatment of some families of products, e.g. linear products (pipes, ducts, cables etc.), is still under review and may necessitate an amendment to this decision.

(1) For homogeneous products and substantial components of non-homogeneous products.

(2) For any external non-substantial component of non-homogeneous products.

(2a) Alternatively, any external non-substantial component having a $PCS \leq 2.0\ MJ.m^{-2}$, provided that the product satisfies the following criteria of EN 13823(SBI) : $FIGRA \leq 20\ W.s^{-1}$; *and* LFS < edge of specimen; *and* $THR_{600s} \leq 4.0$ MJ; *and* s1; *and* d0.

(3) For any internal non-substantial component of non-homogeneous products.

(4) For the product as a whole.

(5) **s1** = $SMOGRA \leq 30m^2.s^{-2}$ *and* $TSP_{600s} \leq 50m^2$; **s2** = $SMOGRA \leq 180m^2.s^{-2}$ *and* $TSP_{600s} \leq 200m^2$; **s3** = not s1 or s2.

(6) **d0** = No flaming droplets/ particles in EN13823 (SBI) within 600s; **d1** = No flaming droplets/ particles persisting longer than 10s in EN13823 (SBI) within 600s; **d2** = not d0 or d1; Ignition of the paper in EN ISO 11925-2 results in a d2 classification.

(7) Pass = no ignition of the paper (no classification); Fail = ignition of the paper (d2 classification).

(8) Under conditions of surface flame attack and, if appropriate to end–use application of product, edge flame attack.

Figure 38 European classification criteria for construction products excluding flooring and linear products (extracted from Sundström, 2007)

APPENDIX M EUROPEAN CLASSIFICATION CRITERIA FOR PIPE INSULATION

Class	Test method(s)	Classification criteria	Additional classification
$A1_L$	EN ISO 1182 (1); And	$T \leq 30°C$; and $m \leq 50\%$; and $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	$PCS \leq 2.0\ MJ.kg^{-1}$ (1); and $PCS \leq 2.0\ MJ.kg^{-1}$ (2); and $PCS \leq 1.4\ MJ.m^{-2}$ (3); and $PCS \leq 2.0\ MJ.kg^{-1}$ (4)	-
$A2_L$	EN ISO 1182 (1); Or	$T \leq 50°C$; and $m \leq 50\%$; and t_f 20s	-
	EN ISO 1716; And	$PCS \leq 3.0\ MJ.kg^{-1}$ (1); and $PCS \leq 4.0\ MJ.m^{-2}$ (2); and $PCS \leq 4.0\ MJ.m^{-2}$ (3); and $PCS \leq 3.0\ MJ.kg^{-1}$ (4)	-
	EN 13823 (SBI)	$FIGRA \leq 270\ W.s^{-1}$; and LFS < edge of specimen; and THR_{600s} 7.5 MJ	Smoke production(5); and Flaming droplets/ particles (6)
B_L	EN 13823 (SBI); And	$FIGRA \leq 270\ W.s^{-1}$; and LFS < edge of specimen; and $THR_{600s} \leq 7.5$ MJ	Smoke production(5); and Flaming droplets/ particles (6)
	EN ISO 11925-2(8): Exposure = 30s	$Fs \leq 150$mm within 60s	
C_L	EN 13823 (SBI); And	$FIGRA \leq 460\ W.s^{-1}$; and LFS < edge of specimen; and $THR_{600s} \leq 15$ MJ	Smoke production(5); and Flaming droplets/ particles (6)
	EN ISO 11925-2(8): Exposure = 30s	$Fs \leq 150$mm within 60s	
D_L	EN 13823 (SBI); And	$FIGRA \leq 2100\ W.s^{-1}$	Smoke production(5); and Flaming droplets/ particles (6)
	EN ISO 11925-2(8): Exposure = 30s	$Fs \leq 150$mm within 60s	
E_L	EN ISO 11925-2(8): Exposure = 15s	$Fs \leq 150$mm within 20s	Flaming droplets/ particles (7)
F_L	No performance determined		

(1) For homogeneous products and substantial components of non-homogeneous products.

(2) For any external non-substantial component of non-homogeneous products.

(3) For any internal non-substantial component of non-homogeneous products.

(4) For the product as a whole.

(5) s1 = $SMOGRA \leq 105\ m^2.s^{-2}$ and $TSP_{600s} \leq 250\ m^2$; s2 = $SMOGRA \leq 580\ m^2.s^{-2}$ and $TSP_{600s} \leq 1600\ m^2$; s3 = not s1 or s2.

(6) d0 = No flaming droplets/ particles in EN13823 (SBI) within 600s; d1 = No flaming droplets/ particles persisting longer than 10s in EN13823 (SBI) within 600s; d2 = not d0 or d1; Ignition of the paper in EN ISO 11925-2 results in a d2 classification.

(7) Pass = no ignition of the paper (no classification); Fail = ignition of the paper (d2 classification).

(8) Under conditions of surface flame attack and, if appropriate to end–use application of product, edge flame attack.

Figure 39 European classification criteria for pipe insulation (extracted from Sundström, 2007)

APPENDIX N RATE OF HEAT RELEASE FOR PIPE INSULATION IN ROOM TESTS

Rate of heat release (HRR) versus time for pipe insulation materials installed in the configuration shown in Figure 8 from reference (Sundström & Axelsson, 2002). The following HRR plots exclude the burner contribution which is 100 kW during the first ten minutes and 300 kW in the period ten to 20 minutes.

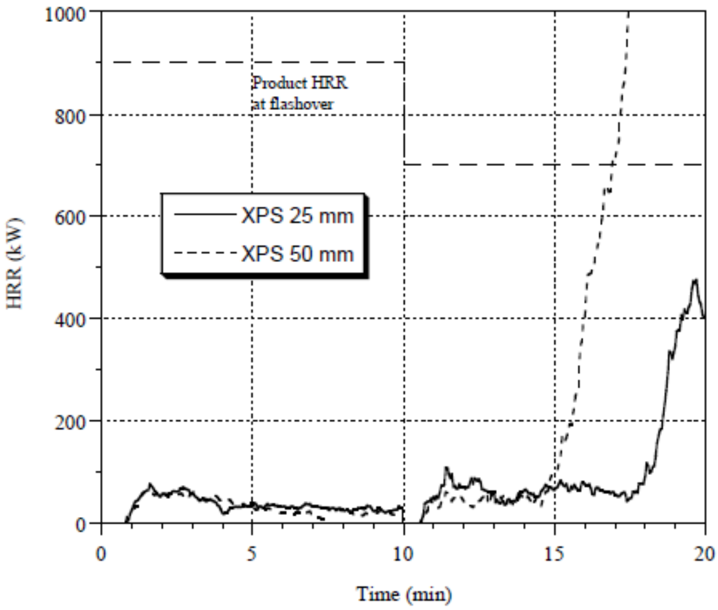

Figure 40 Rate of heat release for unfaced extruded polystyrene at different thickness (extracted from Sundström & Axelsson, 2002)

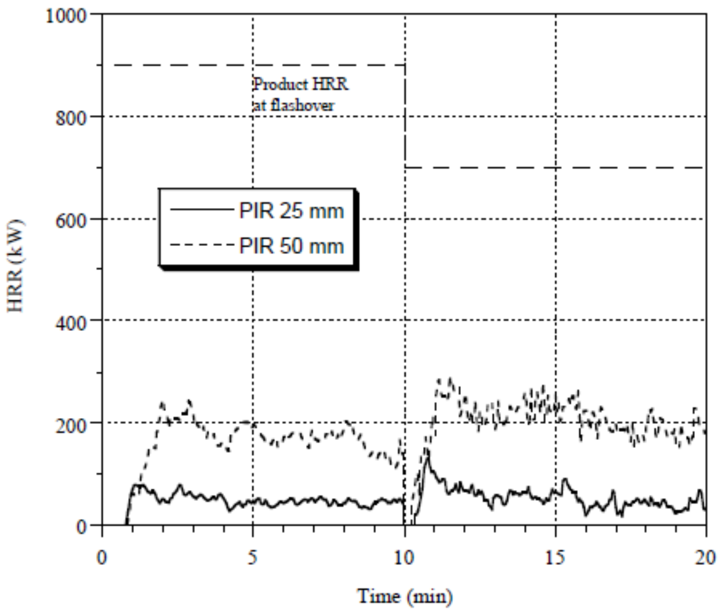

Figure 41 Rate of heat release for rigid polyisocyanurate foam at different thickness (extracted from Sundström & Axelsson, 2002)

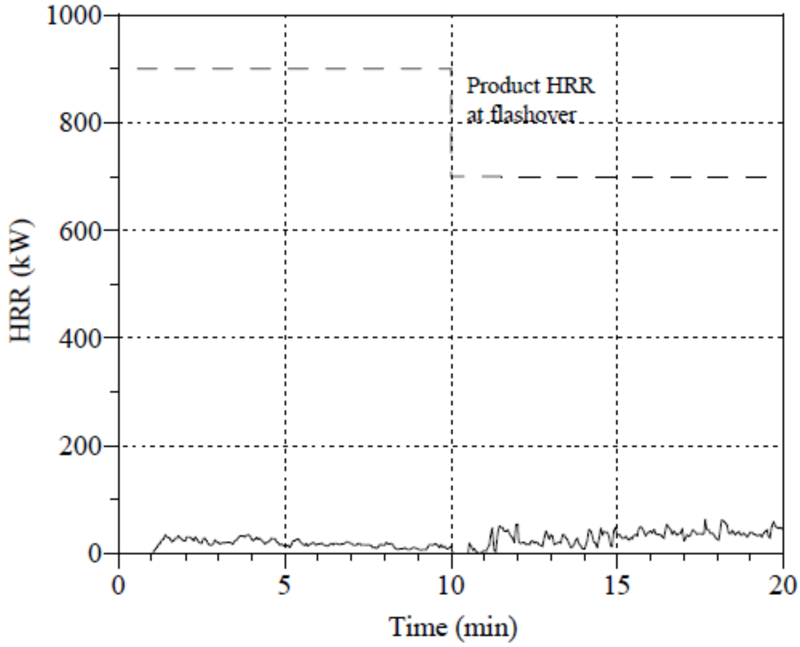

Figure 42 Rate of heat release for 21 mm thick EPS foam pipe insulation (extracted from Sundström & Axelsson, 2002)

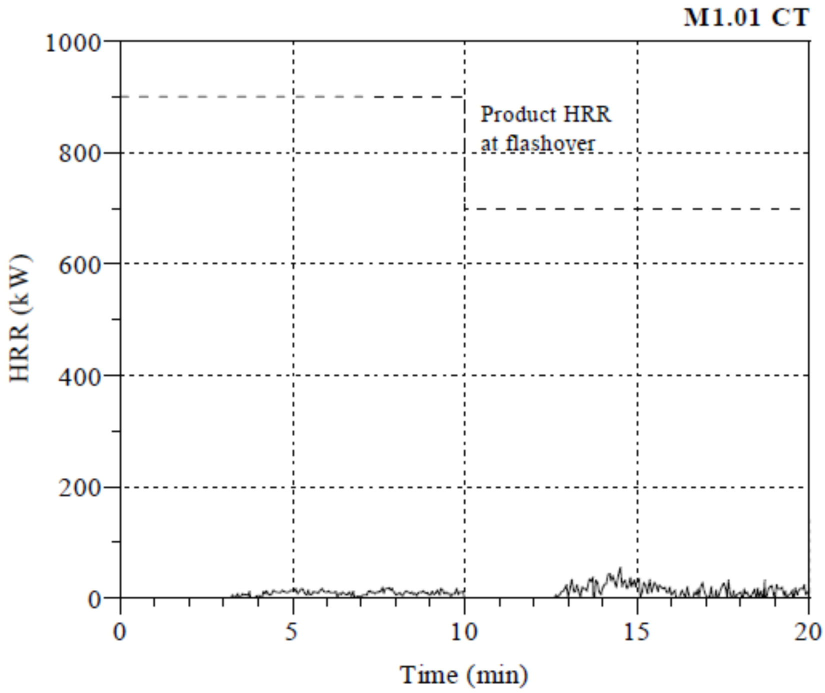

Figure 43 Rate of heat release for aluminium foil cellular glass pipe sections (extracted from Sundström & Axelsson, 2002)

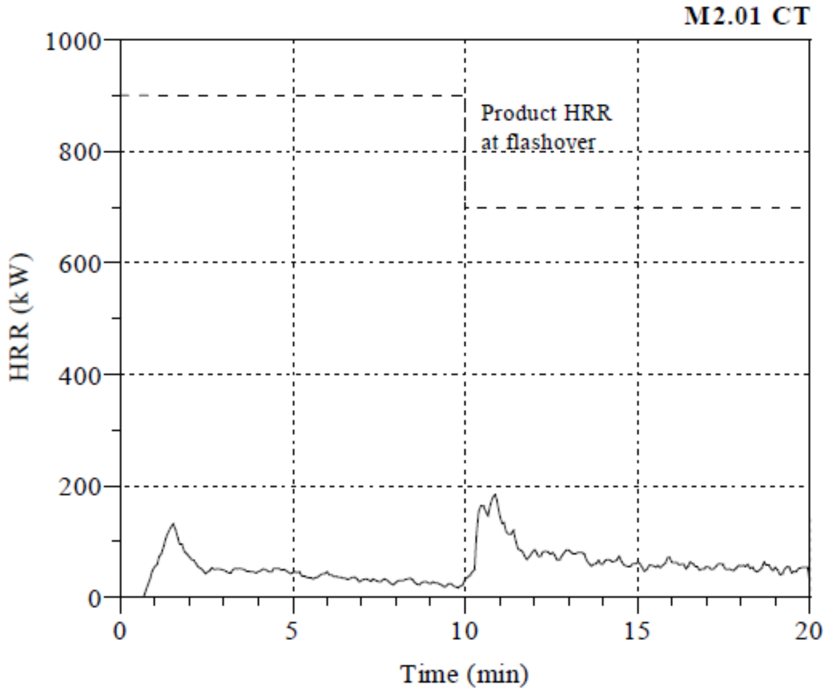

Figure 44 Rate of heat release for PVC film jacketing on mineral wool pipe sections (extracted from Sundström & Axelsson, 2002)

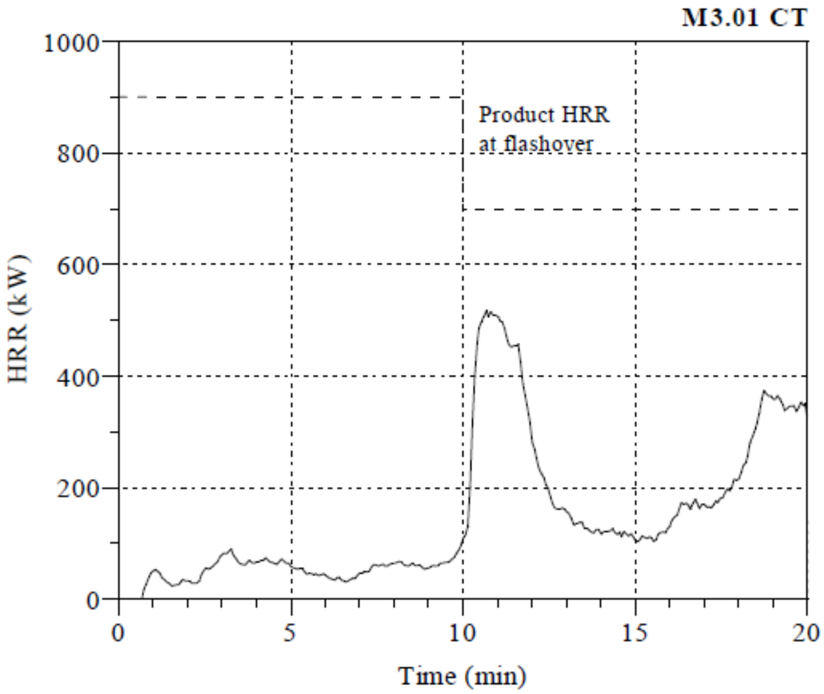

Figure 45 Rate of heat release for unfaced polyethylene foam extruded tubes (extracted from Sundström & Axelsson, 2002)

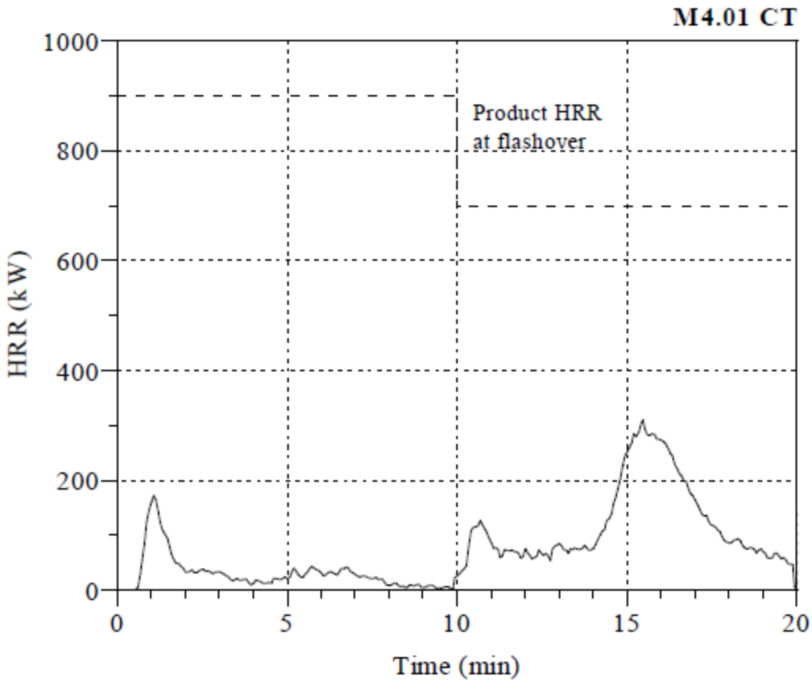

Figure 46 Rate of heat release for unfaced polyethylene foam tubes made from cross-linked sheets (extracted from Sundström & Axelsson, 2002)

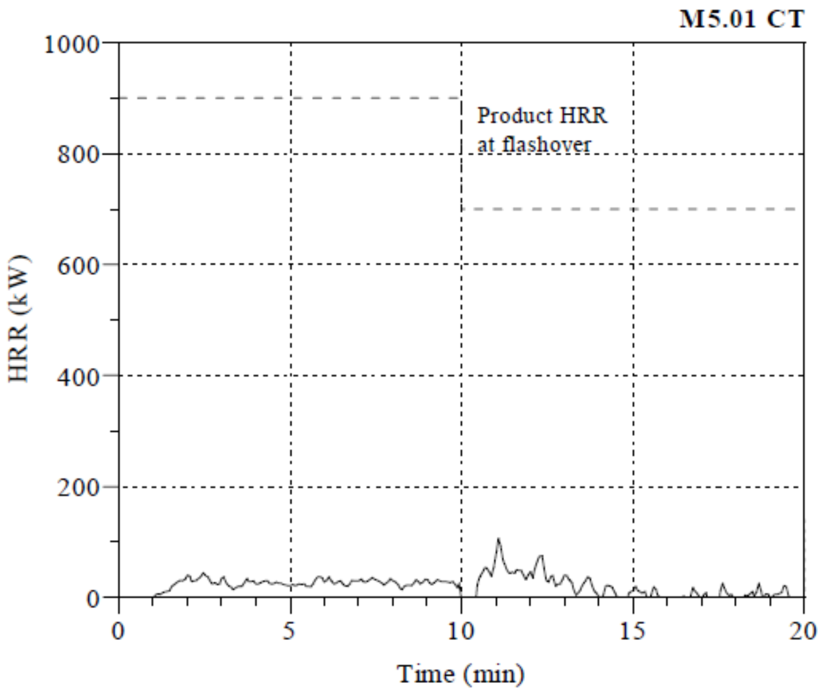

Figure 47 Rate of heat release for unfaced flexible elastomeric foam extruded tubes (extracted from Sundström & Axelsson, 2002)

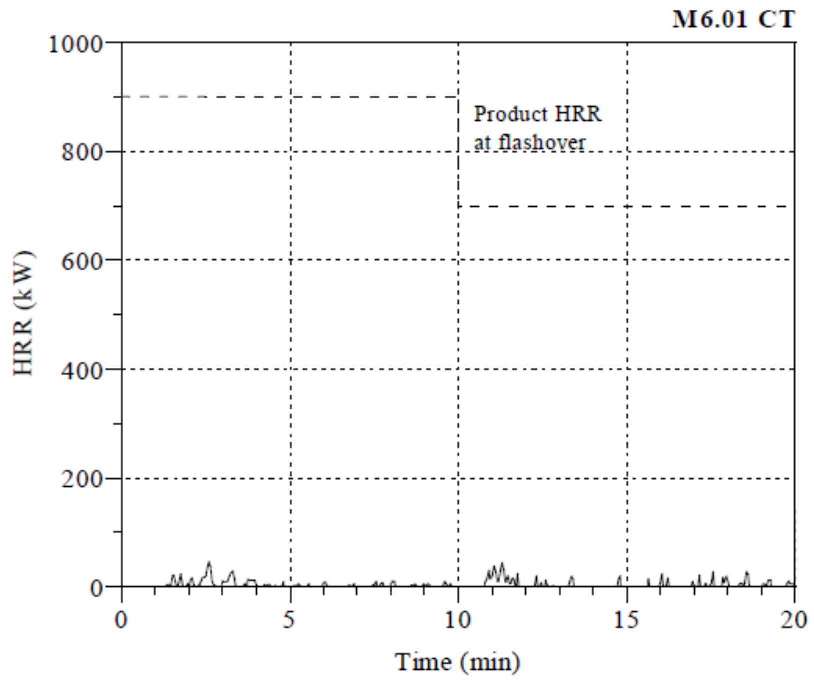

Figure 48 Rate of heat release for aluminium foil-faced mineral wool pipe sections (extracted from Sundström & Axelsson, 2002)

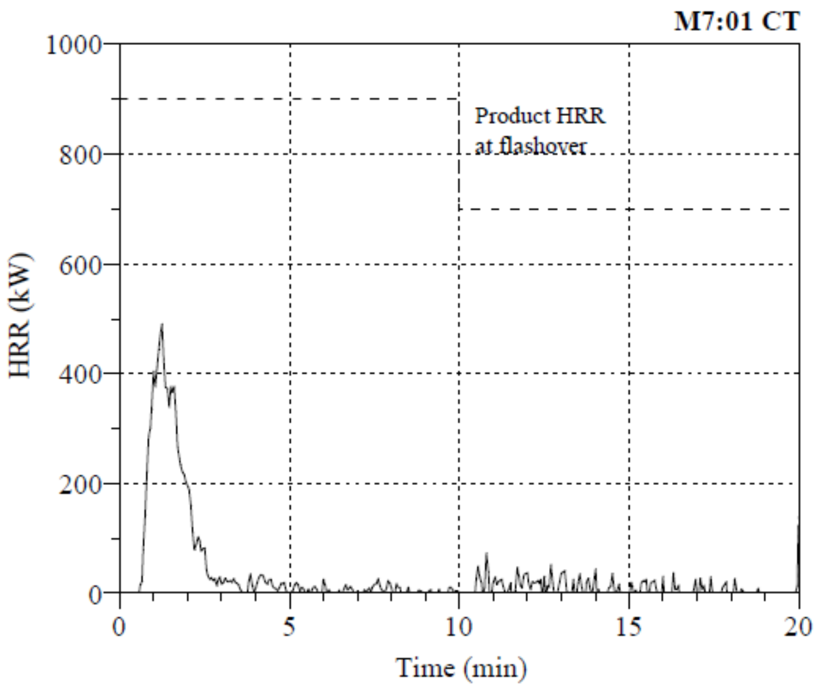

Figure 49 Rate of heat release for semi-rigid extruded polyurethane pipe sections with PVC foil facing (extracted from Sundström & Axelsson, 2002)

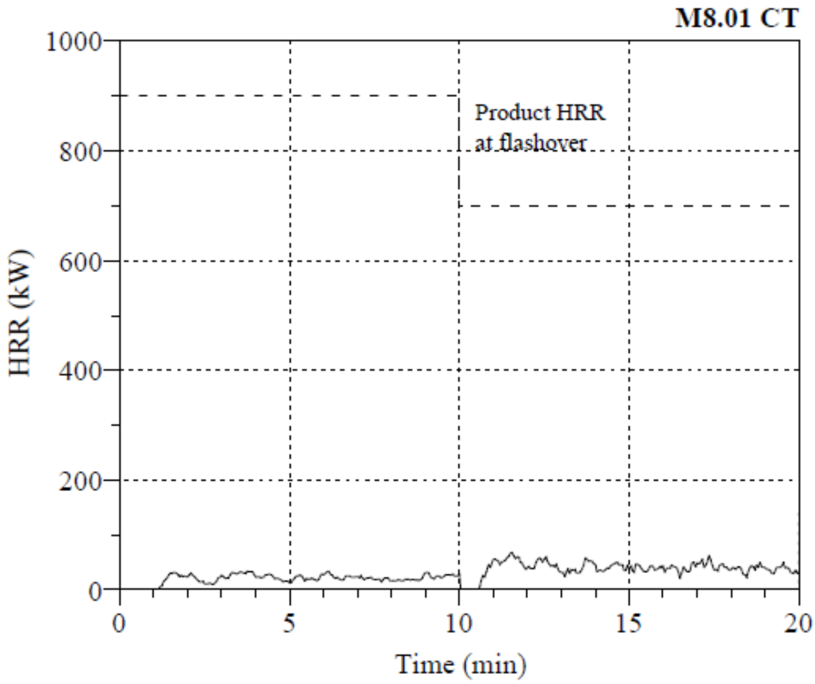

Figure 50 Rate of heat release for unfaced extruded polystyrene foam pipe sections (extracted from Sundström & Axelsson, 2002)

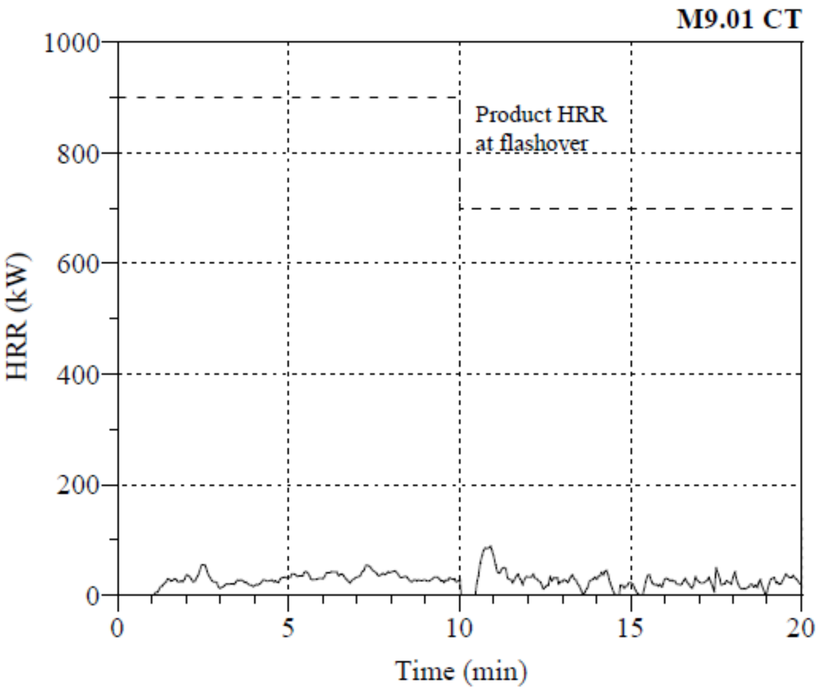

Figure 51 Rate of heat release for rigid polyurethane foam pipe sections (extracted from Sundström & Axelsson, 2002)

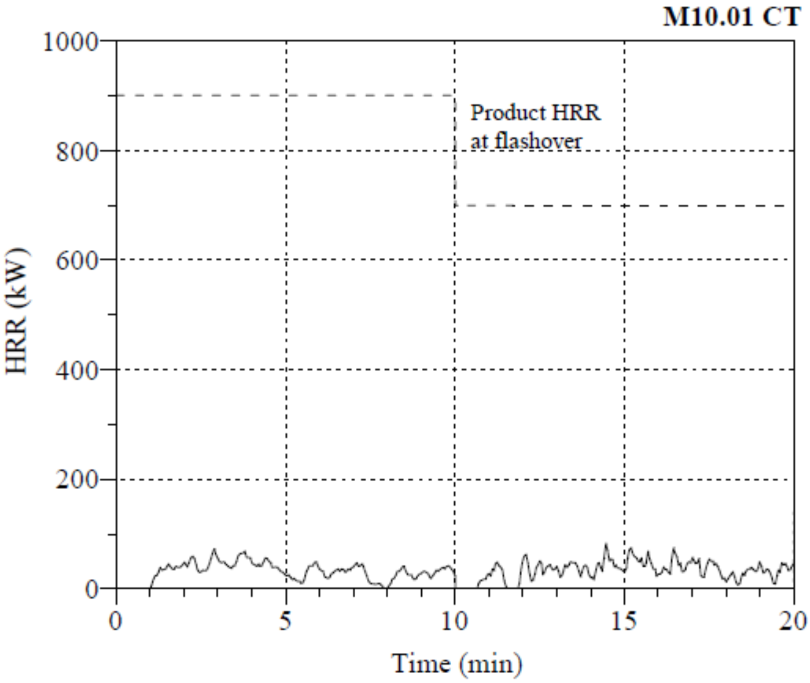

Figure 52 Rate of heat release for unfaced melamine foam pipe sections (extracted from Sundström & Axelsson, 2002)

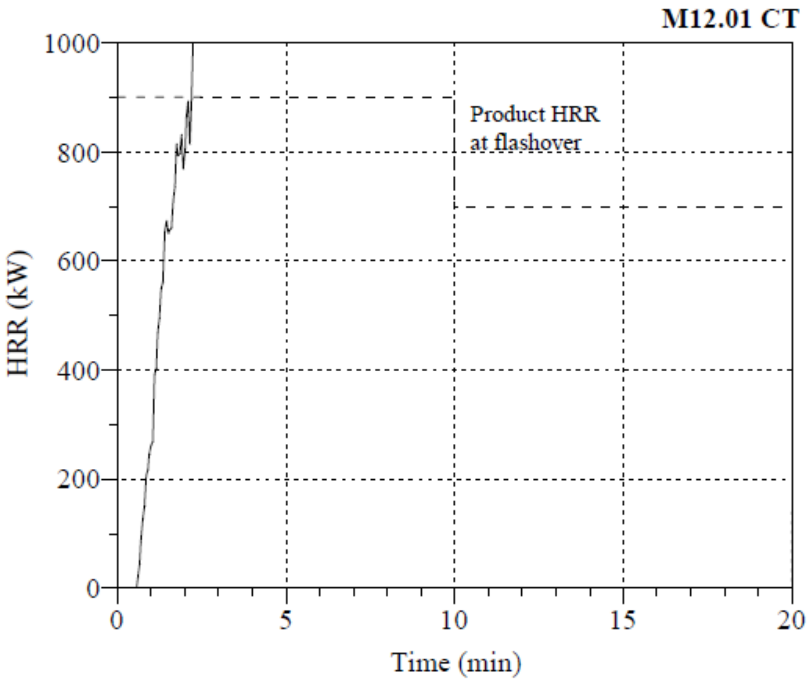

Figure 53 Rate of heat release for unfaced flax fibre pipe sections (extracted from Sundström & Axelsson, 2002)